Final Report to
United States Army
Toxic and Hazardous
Materials Agency
July 1987

Economic Evaluation of Carbon Adsorption/Ion Exchange Wastewater Treatment Options for Sunflower AAP NO Wastewater Treatment Facility

(Task Order Number 4)

Final Report

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Arthur D. Little, Inc.
Contract No. DAAK11-85-D-0008
Reference 54144
USATHAMA Reference AMXTH-TE-CR-87119

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Under Contract No. DAAK11-85-D-0008 with the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), Process Development Branch, Arthur D. Little, Inc. was issued Subtask 5 of Task Order Number 4 entitled "Computerization and Evaluation of a Standard Cost Evaluation Method". The subtask involved carrying out a preliminary engineering design study and cost evaluation for a full-scale nitroguanidine (NQ) wastewater treatment facility at Sunflower Army Ammunition Plant (AAP).

The objective of this subtask was to provide an estimate of the capital investment and operating costs for the wastewater treatment technology option involving activated carbon adsorption and ion exchange for primary separation, and multiple-effect evaporation and spray drying for volume reduction. During the course of this study, however, it became evident that the process economics could be significantly improved if the ion exchange step was eliminated from the process scheme.

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19. (continued)

The bases for the system design, plant operation and cost evaluation were provided to Arthur D. Little by Sunflower AAP personnel to make certain that direct comparisons could be made with other treatment options under consideration.

Performance data from pilot plant testing on actual Sunflower AAP wastewaters were used in designing the carbon adsorption and ion exchange systems. The designs for the multiple-effect evaporator and spray dryer systems were based on common engineering practice. A limited pilot test on simulated feed would be required for the evaporator and spray dryer prior to the final engineering design of these systems.

The capital investment requirement for Case I and Case II are \$6.6 and \$4.6 million (1986 dollars), respectively. The lower capital requirement for Case II results from the elimination of the cation exchange system along with the associated regenerant preparation subsystems, and a smaller capacity spray dryer.

The annual operating costs including variable costs such as utilities, operating materials, labor and off-site disposal, and fixed costs such as plant overhead, maintenance, depreciation, taxes and insurance are \$30 million for Case I and \$7 million per year for Case II. The lower operating cost for Case II results primarily from the elimination of regenerant chemicals associated with the ion exchange operation and the subsequent disposal of these regenerant chemicals as a hazardous waste. It is clear from this study that Case II represents a more plausible process flow scheme from the standpoint of process economics.

If the basic process schemes studied in this task are in the competitive range of other wastewater treatment process technologies being examined by Sunflower AAP, it is highly possible to further optimize the Case II system design and process economics. Improvements may result from the following: 1) increasing the concentration of the brine to the spray dryer which would significantly reduce the size of the downstream spray dryer; 2) adding compaction devices to increase the packing density (decrease the volume) of spray-dried waste materials that require off-site disposal; and/or 3) using a crystallizer/drum dryer system in place of a multiple-effect evaporator/spray dryer system to produce a higher density (less volume) material for off-site disposal.

Keywords.

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1.0 SUMMARY

In October 1986, the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) authorized Arthur D. Little, Inc. to initiate Subtask 5 of Task Order Number 4 entitled "Computerization and Evaluation of a Standard Cost Evaluation Method" under Contract No. DAAK11-85-D-0008. The subtask involved carrying out a preliminary engineering design study and cost evaluation for a full-scale nitroguanidine (NQ) wastewater treatment facility at Sunflower Army Ammunition Plant (AAP).

The objective of this subtask was to provide an estimate of the capital investment and operating costs for the wastewater treatment technology option involving activated carbon adsorption and ion exchange for primary separation, and multiple-effect evaporation and spray drying for volume reduction. Figure 1-1 presents the block flow diagram of the processing sequence studied (Case I).

During the course of this study, however, it became evident that the process economics could be significantly improved if the ion exchange step was eliminated from the process scheme. A block flow diagram illustrating this simplified processing sequence is presented in Figure 1-2, (Case II).

The bases for the system design, plant operation and cost evaluation were provided to Arthur D. Little by Sunflower AAP personnel to make certain that direct comparisons could be made with other treatment options under consideration. Table 1-1 summarizes the design/cost bases for this study.

Performance data from pilot plant testing on actual Sunflower AAP wastewaters were used in designing the carbon adsorption and ion exchange systems. The designs for the multiple-effect evaporator and spray dryer systems were based on common engineering practice. A limited pilot test on simulated feed would be required for the evaporator and spray dryer prior to the final engineering design of these systems.

The capital investment requirement for Case I and Case II are $6.6 and $4.6 million (1986 dollars), respectively. The lower capital requirement for Case II results from the elimination of the cation exchange system along with the associated regenerant preparation subsystems, and a smaller capacity spray dryer. Table 1-2 summarizes the capital investment requirements for both cases.

The annual operating costs including variable costs such as utilities, operating materials, labor and off-site disposal, and fixed costs such as plant overhead, maintenance, depreciation, taxes and insurance are $30 million for Case I, and $7 million per year for Case II as shown in Table 1-3. The lower operating cost for Case II results primarily from the elimination of regenerant chemicals associated with the ion exchange operation and the subsequent disposal of these regenerant chemicals as a hazardous waste. It is clear from this study that Case II represents a more plausible process flow scheme from the standpoint of process economics.

If the basic process schemes studied in this task are in the competitive range of other wastewater treatment process technologies being examined by

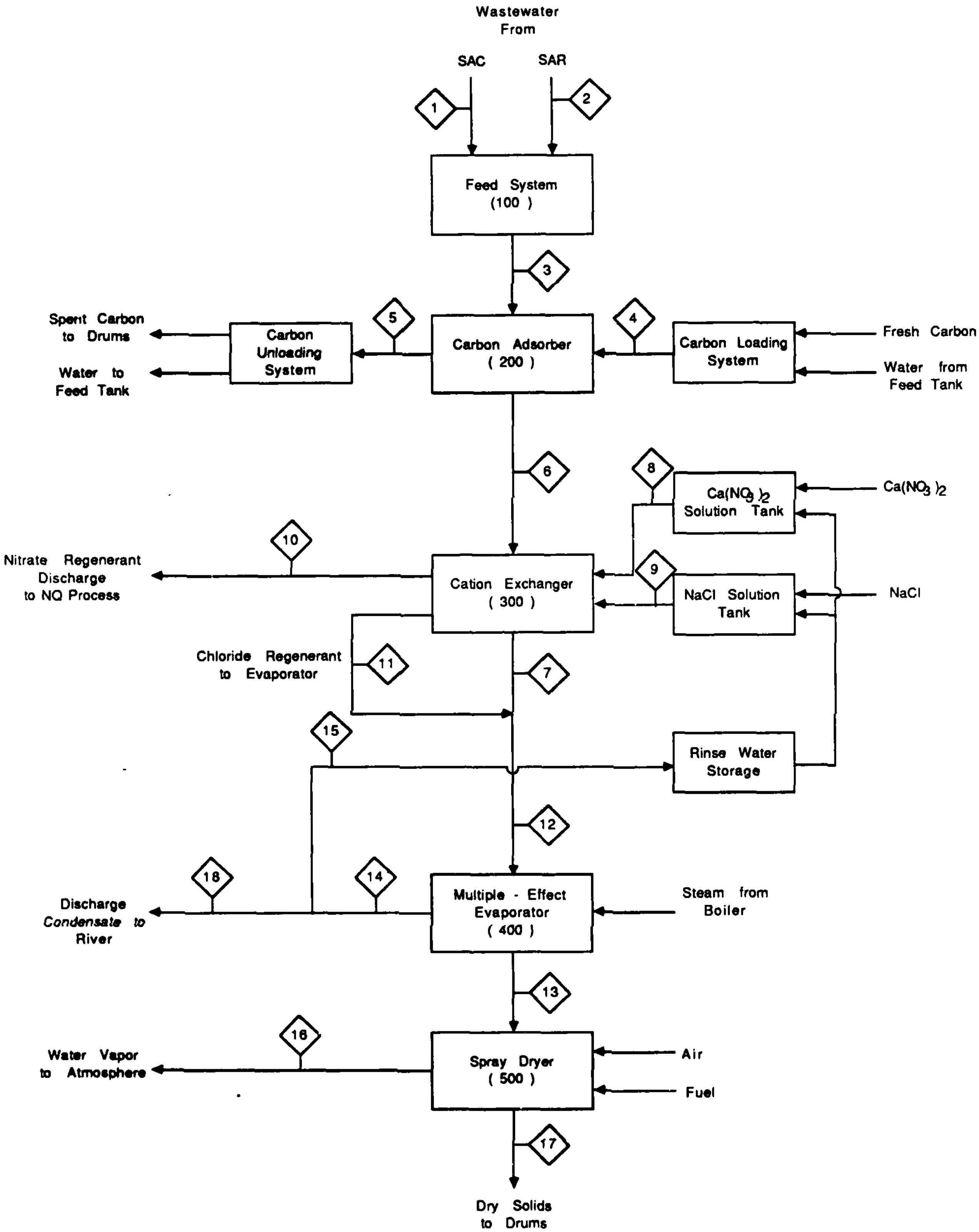

FIGURE 1 - 1
SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
BLOCK FLOW DIAGRAM - CASE 1

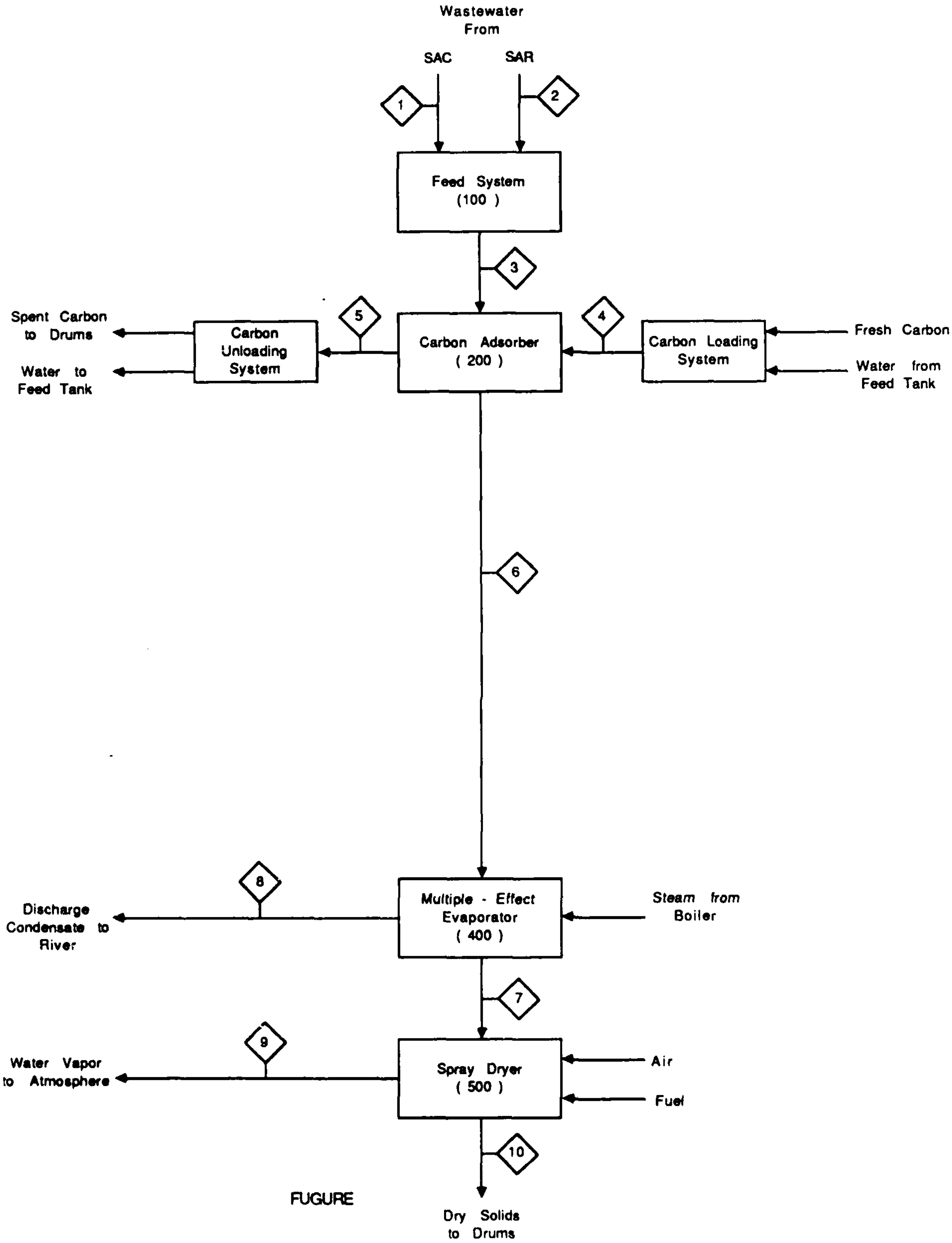

FIGURE 1-2
SUNFLOWER AAP WASTEWATER TREATMENT SYSTEM
BLOCKFLOW DIAGRAM-CASE 2

TABLE 1-1

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
DESIGN/COST BASIS

1. Design Basis:

Stream:	SAC	SAR	Combined
Design Throughput, gal/day:	100,000	100,000	200,000
Stream Composition, mg/l:			
NQ	5.0	0.5	2.8
Gu	26.0	14.0	20.0
NH_3-N	25.0	22.0	23.5
NO_3-N	1,200.0	80.0	640.0
SO_4	1,000.0	1,600.0	1,300.0
Na	220.0	320.0	270.0
Ca	860.0	50.0	455.0
Fe	0.1	0.0	0.1
Cl	11.0	96.0	53.5
pH	7.5	7.5	7.5

2. Plant Operation Basis: Continuous - 24 Hours per Day
7 Days per Week
52 Weeks per Year

3. Cost Evaluation Basis:

Direct Labor (DL), $/hr	17.50
Supervision (S), $/hr	22.00
Overhead, % of DL&S	119.00
Electricity, cents/kWh	5.00
Fuel Gas, $/MMBtu	1.84
Process Water, $/1,000 gals	0.89
Hazardous Waste Disposal, $/55-gal Drum	200.00

Source: Sunflower AAP

TABLE 1-2

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
CAPITAL INVESTMENT SUMMARY - CASE I AND II

System Number	Description	Case I Installed Cost (1986 Dollars)	Case II Installed Cost (1986 Dollars)
100	Feed System	175,000	175,000
200	Carbon Adsorbers	243,000	243,000
300	Cation Exchangers	773,000	0
400	Multiple Effect Evaporator	2,251,000	2,331,000
500	Spray Dryer System	1,682,000	847,000
	TOTAL INSTALLED EQUIPMENT	$5,124,000	$3,596,000
Other	Plant Building	180,000	129,000
	Offices and Laboratories	25,000	25,000
	Office and Lab Equipment	20,000	20,000
	PLANT SUBTOTAL	$5,349,000	$3,770,000
	Engineering Fee (3% of Plant Subtotal)	160,000	113,000
	Contingency (20% of Plant Subtotal)	1,070,000	754,000
	TOTAL CAPITAL INVESTMENT	$6,579,000	$4,637,000

Source: Arthur D. Little, Inc.

TABLE 1-3

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
OPERATING COST SUMMARY - CASE I AND II

Description	Case I Annual Cost (1986 Dollars)	Case II Annual Cost (1986 Dollars)
VARIABLE COSTS		
Utilities	938,000	700,900
Chemicals, Carbon & Resin	8,676,200	273,800
Total Labor	765,400	619,800
Off-Site Disposal	17,337,500	3,869,000
FIXED COSTS		
Plant Overhead (@119% of Total Labor)	910,800	737,600
Maintenance Materials, Labor and Supplies (@4% of Capital Investment)	263,200	185,500
Depreciation (@10% of Capital Investment)	657,900	463,700
Taxes and Insurance (@2% of Capital Investment)	131,600	92,700
TOTAL COST	$29,681,000	$6,943,000

Source: Arthur D. Little, Inc.

Sunflower AAP, it is highly possible to further optimize the Case II system design and process economics. Improvements may result from the following: 1) increasing the concentration of the brine to the spray dryer which would significantly reduce the size of the downstream spray dryer; 2) adding compaction devices to increase the packing density (decrease the volume) of spray-dried waste materials that require off-site disposal; and/or 3) using a crystallizer/drum dryer system in place of a multiple-effect evaporator/spray dryer system to produce a higher density (less volume) material for off-site disposal.

2.0 INTRODUCTION

The nitroguanidine manufacturing facility at Sunflower AAP generates a significant quantity of NQ and guanidine nitrate containing wastewater which is currently being collected in lagoons. USATHAMA desired to evaluate wastewater treatment technology options that would effectively separate valuable constituents in the wastewater from other contaminants for re-use, followed by the landfilling of the contaminants, and subsequent discharge of treated wastewater within National Pollutant Discharge Elimination System (NPDES) permit requirements.

Arthur D. Little, Inc. was contracted by USATHAMA under Contract No. DAAK11-85-D-0008 to evaluate the technical and economic feasibility of the process option involving the use of granular activated carbon (GAC) adsorption and ion exchange (IE) technology to remove NQ, guanidinium (Gu) and ammonia type nitrogen (NH_3-N) from the wastewater. In a previous task (Task Order Number 3), Arthur D. Little, along with its subcontractors, designed and operated a pilot plant at Sunflower AAP to meet the following objectives:

- determine the adsorption capacity of activated carbon for NQ, time required for NQ breakthrough and carbon bed backwash requirements;
- determine the adsorption capacity of ion exchange resin for Gu and NH_3-N, time required for breakthrough and backwash, regeneration and rinse requirements;
- determine the adsorption capacity of ion exchange resin for nitrate type nitrogen (NO_3-N) and sulfates (SO_4), time required for breakthrough and backwash, regeneration and rinse requirements; and
- determine the ability of the GAC/IE System to produce a treated wastewater stream capable of meeting NPDES permit requirements.

During the evaluation of the pilot data, it was determined that the process requirements for anion removal by ion exchange were too onerous to be considered technically feasible due to a high anion concentration in the lagoon wastewater. These anions exist in the wastewater feed as NO_3-N and SO_4. It has since been decided to replace the anion exchange system with a multiple-effect evaporator to produce a dischargeable stream and to use a spray dryer to further reduce the volume of waste (dried salts) for ultimate off-site disposal.

The objective of this task (Task Order Number 4, Subtask 5) was to establish the economic characteristics of GAC/IE in order to allow USATHAMA/Sunflower AAP personnel to make a direct comparison with other technology options. To meet this objective, Arthur D. Little performed preliminary process engineering to develop process flow diagrams, material and energy balances for the process schemes, equipment sizing, component costing, estimates of capital investment, and estimates of operating requirements and costs.

During the course of this study, it became evident that the regeneration of the cation exchange system imposed a significant burden on the system design due to the considerable requirement of operating chemicals (calcium nitrate and sodium chloride). The removal of the cation exchange step not only eliminated the direct costs associated with the cation exchange system, but also reduced the spray dryer requirements, its size and ultimately its cost. More importantly, the total amount of waste material needing ultimate disposal was also reduced. Consequently, two process scenarios were evaluated:

- Case I - Carbon adsorption followed by cation exchange, multiple-effect evaporation and spray drying.
- Case II - Carbon adsorption followed directly by multiple-effect evaporation and spray drying.

3.0 SYSTEM DESCRIPTION AND DESIGN CONSIDERATIONS

3.1 System Description

Based on Sunflower AAP personnel's estimates, the NQ wastewater treatment system was designed to process 200,000 gallons per day of combined wastewater from the SAR and SAC lagoons. It was assumed that the wastewater had been pretreated with lime addition and steam sparging to reduce the concentration level of NQ prior to entering the GAC/IE process unit. The design basis of the system is shown in Table 3-1. It was also assumed that materials removed from the wastewater treatment process are to be disposed of off-site at a secure landfill as a hazardous waste if they cannot be recycled back to the NQ manufacturing process.

3.1.1 Case I System Description

Case I employs carbon adsorption for NQ removal, followed by cation exchange for removal of both Gu and NH_3-N, for subsequent recycle back to the NQ manufacturing process. After removing the cations, the wastewater stream is further treated in a four-effect evaporator which produces a contaminant-free condensate stream and a concentrated brine. The clean condensate stream is suitable for re-use as process water or discharge to the river. The concentrated brine containing 10 wt % soluble salts, is sent to a spray dryer unit which reduces the SO_4, NO_3-N, and chloride salts to dryness. Spray dried salts are packed into 55-gal drums for ultimate disposal in a secure landfill. The system design also includes various subsystems necessary to support main unit operations. These subsystems include feed water surge tanks, activated carbon loading and unloading systems, sodium chloride and calcium nitrate regenerant preparation systems, steam generation system for the evaporator and a combustion system and dust control system for the spray dryer.

With the exception of the spray dryer unit, all equipment was designed for indoor operation. The spray dryer, due to its size, was designed with weatherproofing for outdoor operation. All the combustion equipment required for this system was designed to use natural gas for fuel.

Salt crystals are used for the preparation of sodium chloride regenerant solution, while calcium nitrate solution at 30 wt % concentration, shipped in railroad tankers, is used to prepare the calcium nitrate regenerant. Calcium nitrate is less expensive in solution form than in crystalline form. It is also more convenient to use the calcium nitrate solution in the preparation of regenerant.

Figure 3-1 presents a block flow diagram of the system configuration for Case I. The overall material balance is shown in Table 3-2.

3.1.2 Case II System Description

The Case II system design is similar to that of Case I with the exception that the cation exchange unit and its associated equipment subsystems have been eliminated. The elimination of the cation exchange unit has the following major consequences on the system design:

TABLE 3-1

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM DESIGN BASIS

Stream:	SAC	SAR	Combined
Design Throughput, gal/day:	100,000	100,000	200,000
Stream Composition, mg/l:			
NQ	5.0	0.5	2.8
Gu	26.0	14.0	20.0
NH_3-N	25.0	22.0	23.5
NO_3-N	1,200.0	80.0	640.0
SO_4	1,000.0	1.600.0	1,300.0
Na	220.0	320.0	270.0
Ca	860.0	50.0	455.0
Fe	0.1	0.0	0.1
Cl	11.0	96.0	53.5
pH	7.5	7.5	7.5

Plant Operation Basis: Continuous - 24 Hours per Day
7 Days per Week
52 Weeks per Year

Source: Sunflower AAP

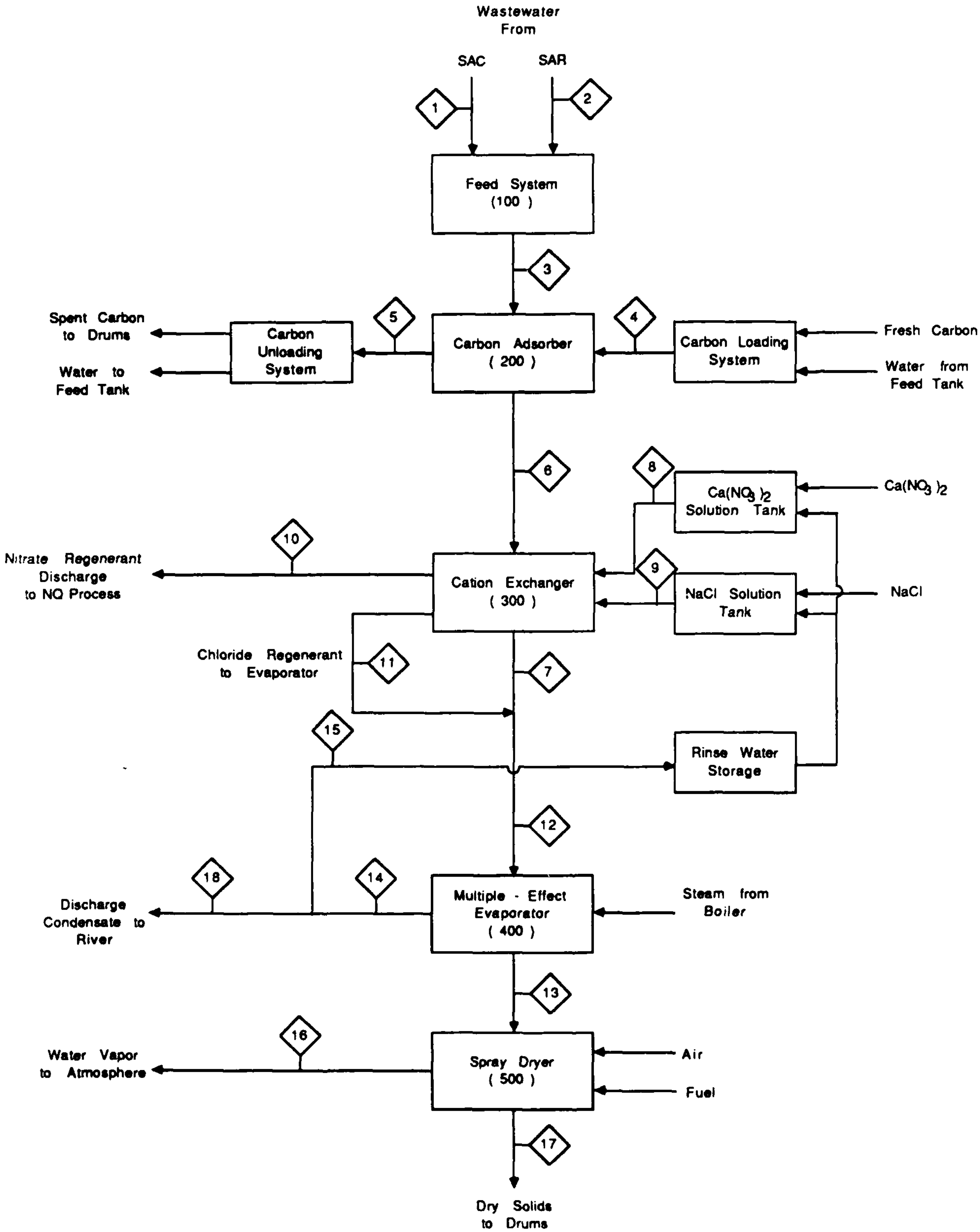

FIGURE 3-1
SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
BLOCK FLOW DIAGRAM - CASE 1

TABLE 3-2

THAMA SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
-----OVERALL MATERIAL BALANCE **(IN THOUSAND POUNDS PER DAY)-----
(CASE I)

STREAM #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
LOCATION	WASTE WATER FR SAC	WASTE WATER FR SAC	INLET TO CARBON SYSTEM	CARBON LOADING SYSTEM	CARBON UNLOAD SYSTEM	FEED TO CATION BED	CATION BED DISCHARGE	NITRATE REGEN SOLUTION	CHLORIDE REGEN SOLUTION	NITRATE REGEN DISCHARGE	CHLORIDE REGEN TO M-E EVAP	FEED TO M-E EVAPORAT	M-E EVAPORAT BRINE	CONDENSAT FROM M-E EVAP	RINSE WATER USE	WATER VAPOR FR SPRAY DRY	SOLIDS DISCHARGE TO DRUM	CONDENSAT TO DISCHARGE
NQ	0.0042	0.0004	0.0046	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gu	0.0217	0.0117	0.0334	0.000	0.000	0.033	0.000	0.000	0.000	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NH_3-N	0.0209	0.0183	0.0392	0.000	0.000	0.039	0.000	0.000	0.000	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	0.1830	0.2670	0.4500	0.000	0.000	0.450	0.525	0.000	13.529	3.300	10.154	10.679	10.679	0.000	0.000	0.000	10.679	0.000
Ca	0.7170	0.0420	0.7590	0.000	0.000	0.759	0.759	10.987	0.000	8.050	2.937	3.696	3.696	0.000	0.000	0.000	3.696	0.000
NO_3*	4.4330	0.2970	4.7300	0.000	0.000	4.730	4.730	34.060	0.000	34.061	0.000	4.730	4.730	0.000	0.000	0.000	4.730	0.000
SO_4	0.8340	1.3340	2.1680	0.000	0.000	2.168	2.168	0.000	0.000	0.000	0.000	2.168	2.168	0.000	0.000	0.000	2.168	0.000
Cl	0.0092	0.0801	0.0893	0.000	0.000	0.089	0.089	0.000	20.881	0.000	20.880	20.970	20.970	0.000	0.000	0.000	20.970	0.000
TOTAL IONS	6.2230	2.0505	8.2735	0.000	0.000	8.268	8.271	45.047	34.410	45.483	33.971	42.243	42.243	0.000	0.000	0.000	42.243	0.000
WATER	834.000	834.000	1668.000	5.000	5.000	1668.000	1668.000	406.000	195.000	421.000	210.000	1878.000	380.187	1497.813	631.000	380.187	0.000	866.813
TOTAL	840.2230	836.0505	1676.2735	5.000	5.000	1676.268	1676.271	451.047	229.410	466.483	243.971	1920.243	422.430	1497.813	631.000	380.187	42.243	866.813
% SOLID	0.74	0.25	0.49	0.00	0.00	0.49	0.49	9.99	15.00	9.75	13.92	2.20	10.00	0.00	0.00	0.00	100.00	0.00

NOTES

* ASSUMES NO_3-N IS PRESENT AS EQUIVALENT NO_3

** NO ION BALANCE, AS ANION/CATIONS RATIO IS 2:1 IN THE FEED
FIGURES PROVIDED BY SFAAP

- Gu and NH_3-N are not recovered for recycle back to the NQ manufacturing process;

- Gu and NH_3-N are removed as dried salts for off-site disposal;

- chemical (calcium nitrate and sodium chloride) addition requirements are eliminated from this portion of the wastewater treatment facility;

- feed to the multi-effect evaporator is less concentrated; and

- spray dryer throughput is reduced with subsequent reduction in the energy requirement and the total amount of dried solids that need to be disposed as a hazardous waste.

Figure 3-2 presents the system block diagram for Case II. The overall material balance for Case II is shown in Table 3-3.

3.2 Design Considerations

The NQ wastewater treatment system is divided into subsystems as shown below:

- System 100 - Feed System

- System 200 - Carbon Adsorption and Compressed Air Station

- System 300 - Cation Exchange and Regenerant Preparation Units

- System 400 - Multiple-Effect Evaporator and Steam Generator

- System 500 - Spray Dryer and Dried Salts Drumming Station

Design considerations for each of the subsystems for both Case I and Case II are described in the following sections. Detailed lists of system components can be found in Table A-1 for Case I and Table A-2 for Case II in Appendix A.

3.2.1 Feed System (System 100)

The feed system consists of a pair of feed transfer pumps for transferring wastewater separately from SAR and SAC lagoons, to a pair of separate feed surge tanks and a feed charging pump (with an installed full-capacity spare).

Each feed transfer pump is designed to transfer 100,000 gallons of wastewater per day (70 gpm) and is provided with a strainer and a cartridge filter. The feed transfer pumps and filter housings are made of rubber-lined carbon steel and piping is specified to be PVC.

Feed surge tanks, one for the SAR stream and the other for the SAC stream, each with 24,000 gallons nominal capacity, provide approximately 5.7 hours of surge capacity for each stream at the design flow rate. The surge tanks are constructed of fiberglass.

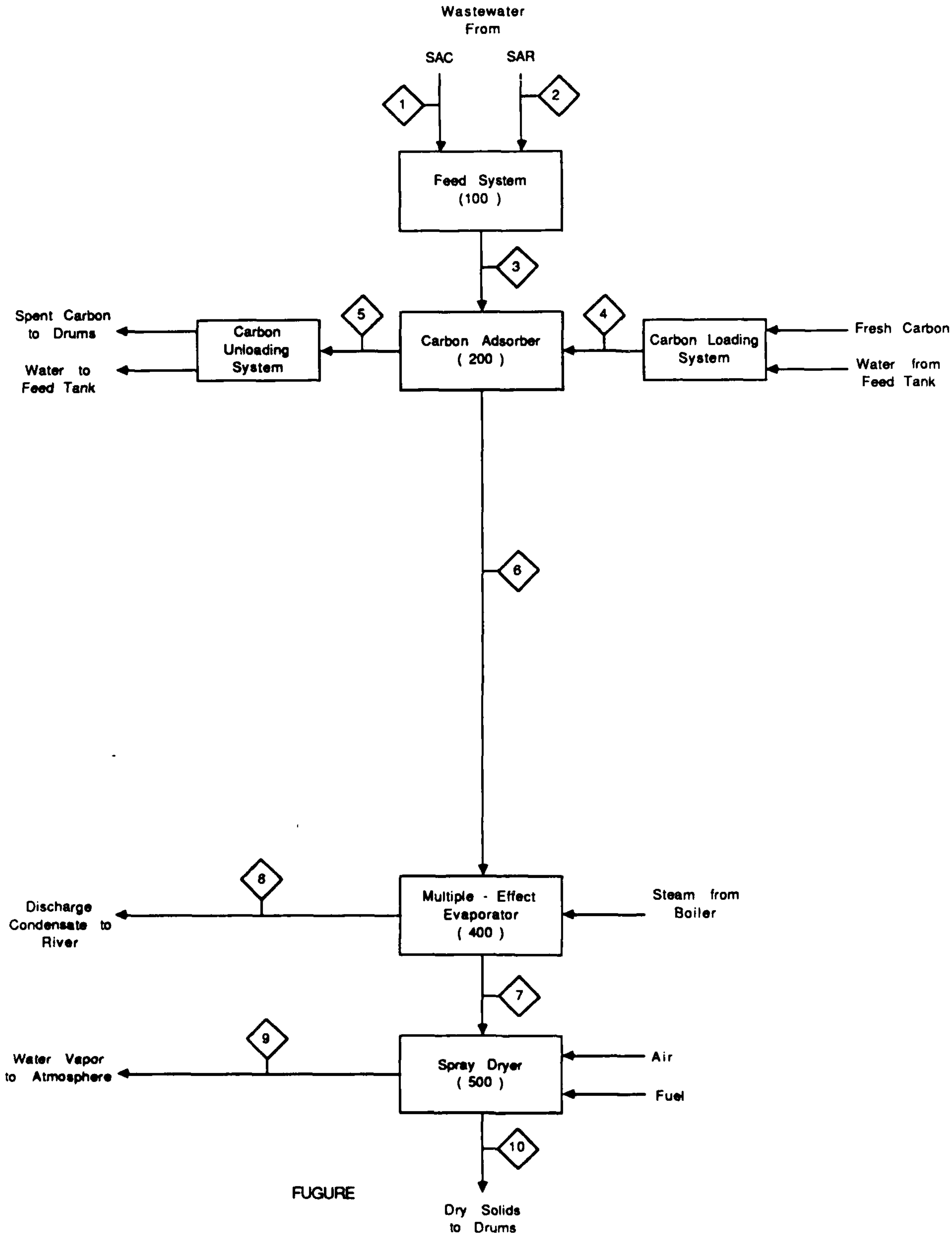

FIGURE 3-2
SUNFLOWER AAP WASTEWATER TREATMENT SYSTEM
BLOCKFLOW DIAGRAM-CASE 2

TABLE 3-3

THAMA SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
-----OVERALL MATERIAL BALANCE **(IN THOUSAND POUNDS PER DAY)-----
(CASE II)

STREAM #	1	2	3	4	5	6	7	8	9	10
LOCATION	WASTE WATER FR SAC	WASTE WATER FR SAC	INLET TO CARBON SYSTEM	CARBON LOADING SYSTEM	CARBON UNLOAD SYSTEM	FEED TO M-E EVAP	M-E EVAPORAT BRINE	CONDENSAT FROM M-E EVAP	WATER VAPOR FR SPRAY DRY	SOLIDS DISCHARGE TO DRUM
NQ	0.0042	0.0004	0.0046	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gu	0.0217	0.0117	0.0334	0.000	0.000	0.033	0.033	0.000	0.000	0.033
NH3-N	0.0209	0.0183	0.0392	0.000	0.000	0.039	0.039	0.000	0.000	0.039
Na	0.1830	0.2670	0.4500	0.000	0.000	0.450	0.450	0.000	0.000	0.450
Ca	0.7170	0.0420	0.7590	0.000	0.000	0.759	0.759	0.000	0.000	0.759
NO3*	4.4330	0.2970	4.7300	0.000	0.000	4.730	4.730	0.000	0.000	4.730
SO4	0.8340	1.3340	2.1680	0.000	0.000	2.168	2.168	0.000	0.000	2.168
Cl	0.0092	0.0801	0.0893	0.000	0.000	0.089	0.089	0.000	0.000	0.089
TOTAL IONS	6.2230	2.0505	8.2735	0.000	0.000	8.268	8.268	0.000	0.000	8.268
WATER	834.000	834.000	1668.000	5.000	5.000	1668.000	78.120	1589.880	78.120	0.000
TOTAL	840.2230	836.0505	1676.2735	5.000	5.000	1676.268	86.388	1589.880	78.120	8.268
% SOLID	0.74	0.25	0.49	0.00	0.00	0.49	9.57	0.00	0.00	100.00

NOTES
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* ASSUMES NO3-N IS PRESENT AS EQUIVALENT NO3

** NO ION BALANCE, AS ANION/CATIONS RATIO IS 2:1 IN THE FEED
FIGURES PROVIDED BY SFAAP

Wastewater from the SAR and SAC lagoons is combined prior to entering the feed charging pump which is designed to deliver 140 gpm of wastewater with sufficient head to overcome the flow resistance in the downstream equipment. The feed charging pump and its installed spare are made of rubber-lined steel and are provided with redundant pre-filters.

Figure 3-3 presents a process flow diagram for the feed system. The feed system is identical for both Case I and Case II.

3.2.2 Carbon Adsorption System (System 200)

The carbon adsorption system consists of a two-adsorber unit, a carbon slurrying system for loading fresh activated carbon, a spent carbon dewatering unit and a compressed air station, as shown in Figure 3-4. The two activated carbon adsorbers, each with a 4 ft diameter and an 8 ft straight-side length, are made of epoxy-lined carbon steel and equipped with manual flow directional valves and PVC piping. Each adsorber can contain 5,000 lbs of Calgon Filtrasorb 300 activated carbon and is designed to be on-stream for 5 days.

The carbon system is designed to be non-regenerative. Spent carbon is to be removed from the adsorbers by pressure transfer using compressed air as the source of pressure. Spent carbon, after draining of free water in a bulk bin, can be either shipped in bulk or re-packaged into 55-gallon drums for off-site disposal.

Fresh carbon is slurried in the bulk bin and transferred to the adsorber by eduction with high pressure water supplied by the carbon slurrying pump.

A compressed air station is provided with the system to facilitate the removal of spent carbon as well as to supply instrument air and plant air required for operating the NQ wastewater treatment facility. A 125 gallon air receiver and a heatless desiccant dryer are included in the compressed air station.

Carbon bed sizing calculations are shown in Table B-1, Appendix B. The carbon adsorption system is identical for both Case I and Case II.

3.2.3 Cation Exchange System (System 300)

The cation exchange system (Figure 3-5) includes two resin beds with regenerant preparation systems for both sodium chloride and calcium nitrate rinses.

The resin beds are operated in parallel and designed to hold 420 cubic feet of Rohm and Haas Amberlite IR-120 cation resin. The resin bed vessel is 10 ft in diameter, 9 ft in straight-side length and is made of carbon steel with a coating of baked phenolic resin for corrosion resistance. The resin bed vessels are sized for a bed expansion ratio of 1.5 during the backwash operation.

Each resin bed is designed to be on-stream for 8 hours. A complete cycle (16 hours) of the resin bed operation includes:

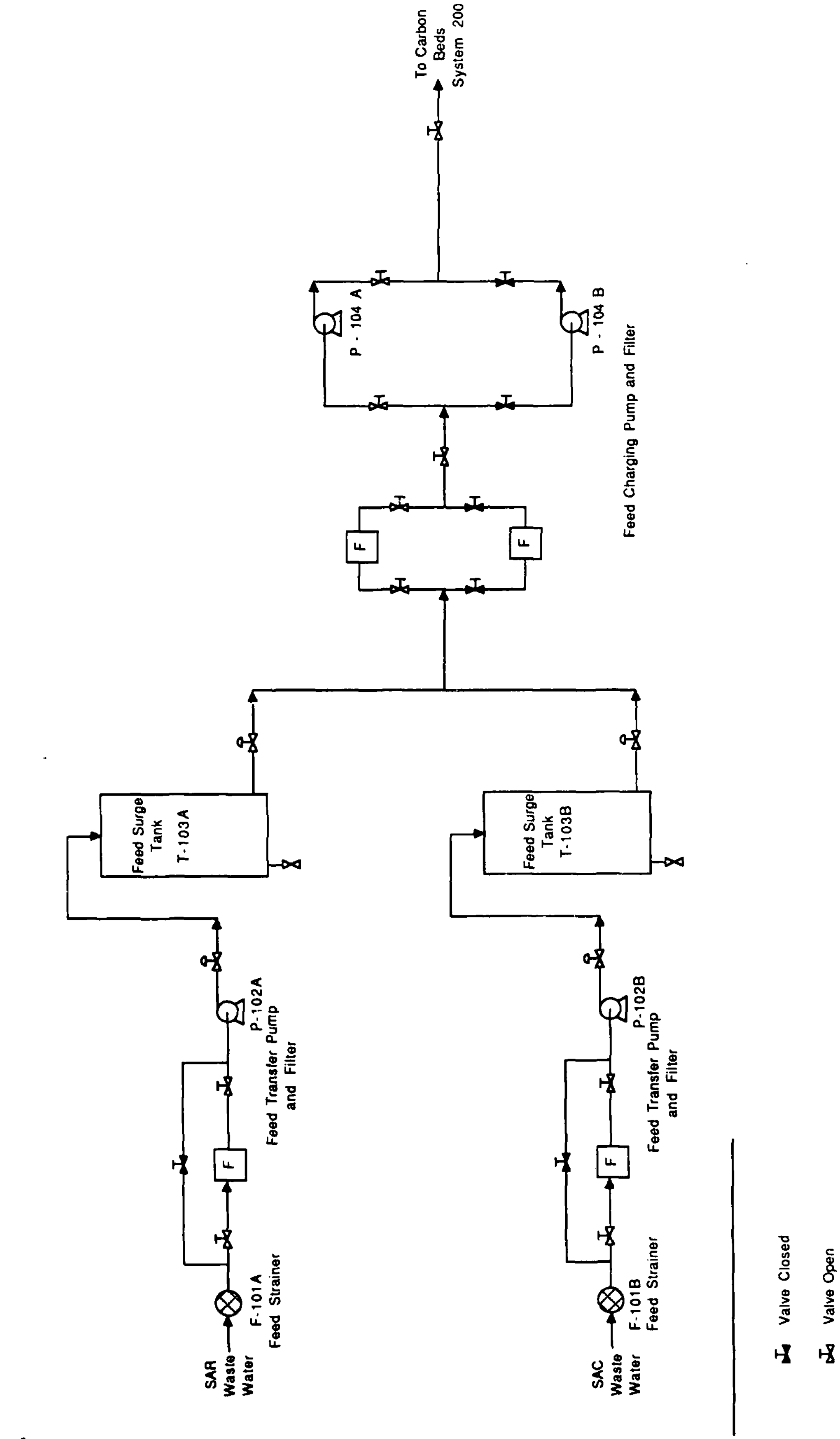

FIGURE 3 - 3
SYSTEM 100 - FEED SYSTEM

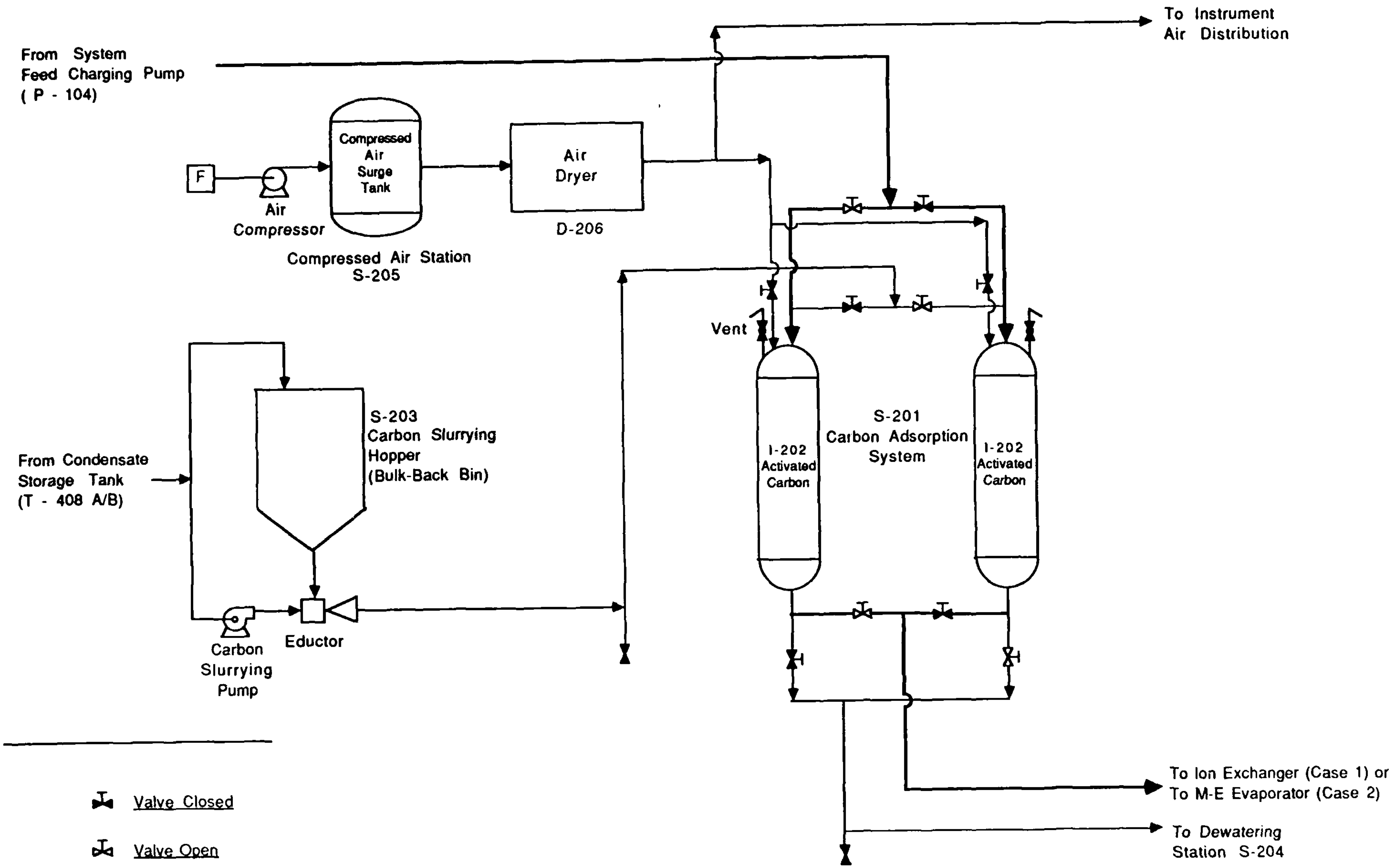

FIGURE 3-4
SYSTEM 200- CARBON ADSORPTION SYSTEM

a) Adsorption, (downflow), 8 hours;

b) Backwash, (upflow), 0.5 hour;

c) Calcium Nitrate Regeneration, (upflow), 4 hours;

d) Sodium Chloride Regeneration, (upflow), 2 hours;

e) Water Rinse, (upflow), 1 hour; and

f) Standby, 0.5 hour.

The ion exchange beds are designed to switch automatically (spent bed to a fresh bed) by an adjustable timer/sequencer. Sizing calculations of the ion exchange bed are included in Table B-2, Appendix B. The wastewater from the cation exchange system is then further processed in the multiple-effect evaporator (System 400).

The 10 wt % calcium nitrate regenerant solution is prepared by diluting a 30 wt % solution of calcium nitrate with evaporator condensate. The 30 wt % calcium nitrate solution is shipped by railroad tanker and pumped to a 30,000 gallon calcium nitrate concentrate tank for storage. During the calcium nitrate regeneration cycle, calcium nitrate will be pumped from the concentrate storage tank into the ion exchange bed after an in-line dilution with evaporator condensate. The spent regenerant solution, along with eluted Gu and NH_3-N, is sent back to the NQ manufacturing process (see Table 3-2 for its concentration).

Following the calcium nitrate regeneration, the resin bed is rinsed with a 10 wt % sodium chloride solution to further regenerate the cation resin and place the resin in the more effective sodium form. Sodium chloride will be purchased as salt crystals, delivered to the plant by bulk hopper trucks and unloaded into an epoxy-coated concrete pit. The crystal salt is then transferred into one of the two salt solution tanks via a tube conveyor (Figure 3-5). Saturated salt solution (36 wt % at room temperature) is made in the salt solution tank by flooding the lower portion of the tank with evaporator condensate. During the sodium chloride regeneration cycle, 40 gpm of the sodium chloride concentrate is pumped from the concentrate tank, after an in-line dilution with 104 gpm of evaporator condensate, to the ion exchange resin bed. The solution level in the concentrate tank is maintained by adding 40 gpm of evaporator condensate for the duration of this operation. Spent chloride regenerant is sent to the multiple-effect evaporator system. We have assumed the worse case scenario; the spent chloride regenerant can not be discharged to the river.

After the sodium chloride regeneration, the resin bed is rinsed with evaporator condensate to remove residual sodium chloride left in the pores of the resin bed.

The double regeneration process is included in the process for the following two reasons:

1) Amberlite IR-120 resin is most effectively regenerated with sodium ion; and

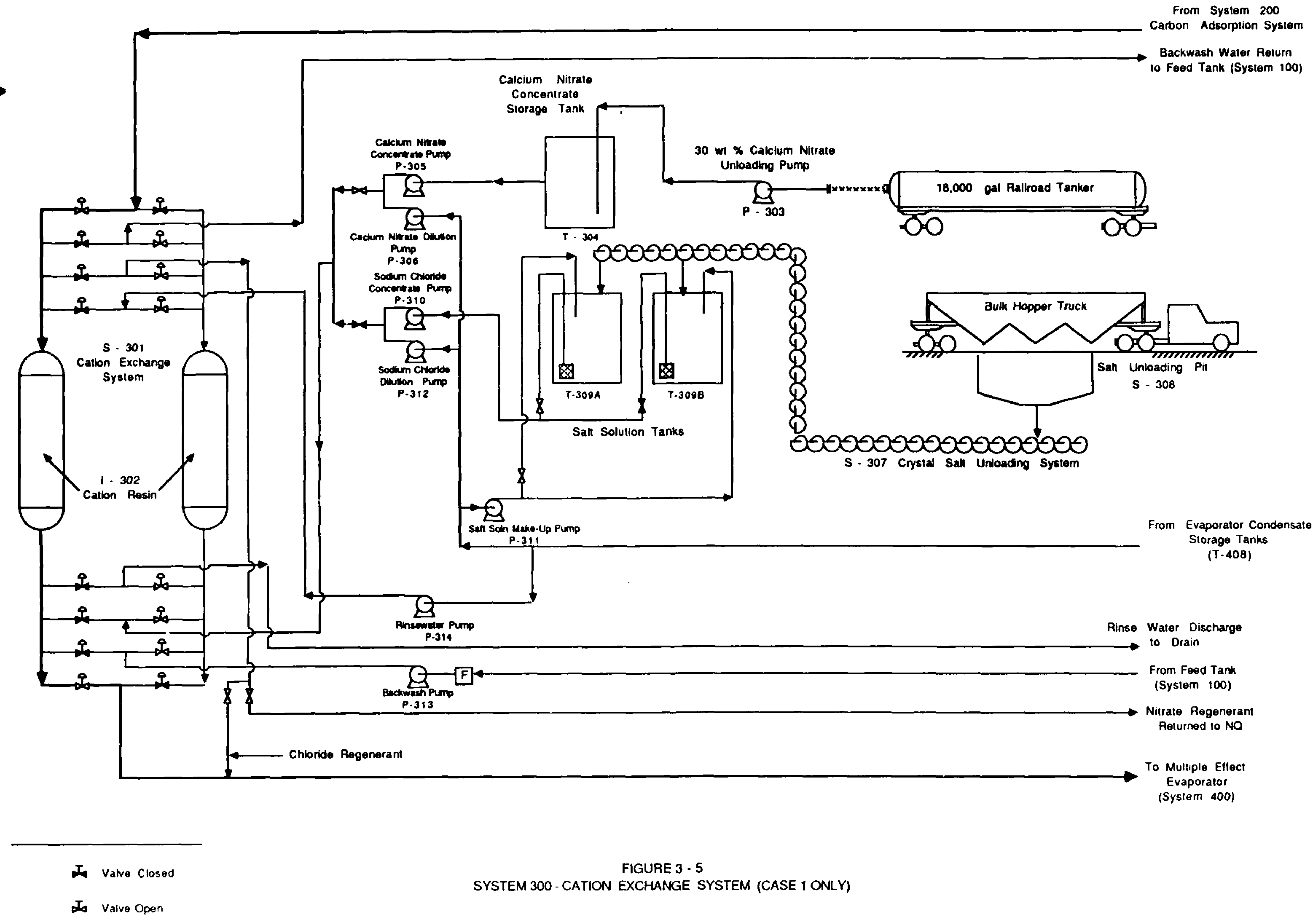

FIGURE 3 - 5
SYSTEM 300 - CATION EXCHANGE SYSTEM (CASE 1 ONLY)

2) It is more desirable to recover the Gu and NH_3-N ions in the form of nitrate for the purpose of re-use in the NQ manufacturing process.

Provisions are made for backwashing the resin bed to remove solid materials prior to chemical regeneration. Since the cycle time is relatively short (8 hours) and the wastewater had been filtered in the feed system, as well as pretreated in the carbon system, it may only be necessary to activate the backwash step when the pressure drop in the resin bed becomes significant in order to avoid unnecessary generation of wastewater.

Calculations related to resin bed regeneration can be found in Table B-3, Appendix B.

In reviewing the system design, it becomes obvious that the cation exchange system recovers a mere 33 lbs of Gu and 39 lbs of NH_3-N per day while consuming 45,000 lbs of calcium nitrate and 34,400 lbs of sodium chloride during the same period; with much of these chemical additions requiring ultimate disposal.

In the Case II process scenario, we propose to eliminate the cation exchange system and associated equipment.

3.2.4 Multiple-Effect Evaporator (System 400)

The objective of this waste treatment facility is to minimize or eliminate the amount of effluent discharged to the environment and to ensure that only liquid effluents meeting NPDES permit requirements are discharged. Therefore, the salts in the cation exchange effluent and the spent chloride regenerant solution must be separated from the treated wastewater and disposed of. Multiple-effect evaporation followed by spray drying was identified as the technology most appropriate to accomplish this objective.

To maximize the performance of the spray dryer, it would require an inlet solution stream having a solids concentration as high as possible. Presently, the chemistry of the ion interactions in the evaporator feed stream are not fully understood; consequently, we conservatively selected an evaporator bottoms concentration of 10 wt % representing, in our judgment, the concentration of salts which can be attained without the threat of crystallization in the evaporator and/or sulfate scaling of the heat exchange surface.

A process flow diagram of the multiple-effect evaporator system is presented in Figure 3-6. The system is essentially made up of four components:

- four-effect evaporator,
- feed preheater,
- steam boiler, and
- ancillary equipment such as tanks and pumps.

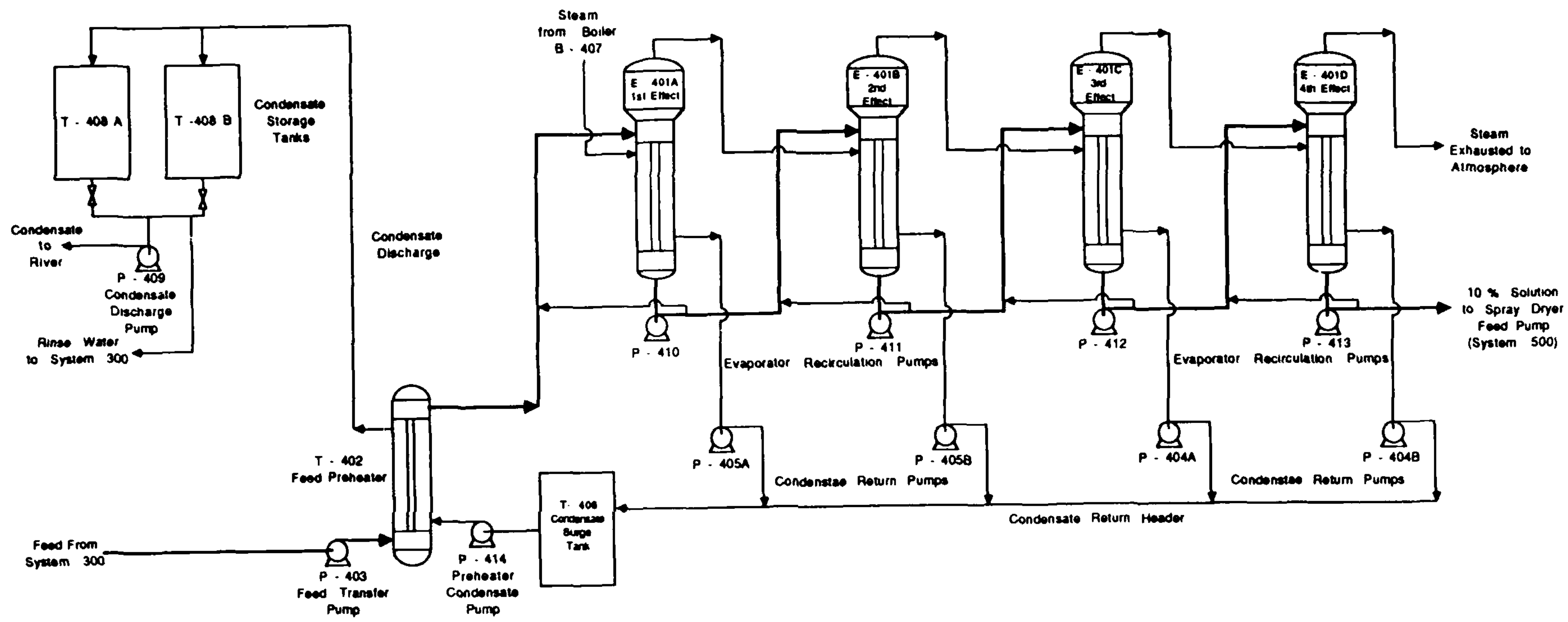

FIGURE 3 - 6
SYSTEM 400 - MULTIPLE EFFECT EVAPORATOR

In Case I, the feed solution is transferred from the cation exchange system at 60°F and preheated to 180°F in a shell-and-tube type feed preheater with steam condensate from the evaporator. The condensate is then pumped to the condensate storage tanks where it is held for further use in the process or discharged to the river.

The preheated feed is pumped to the tube side of the first effect. Saturated steam from the boiler at 180 psia (370°F) is supplied to the shell side of the first effect where it condenses. Steam generated by evaporation of the feed stream in the first effect is used as the heating medium in the second effect, while the bottom discharge from the first effect is transferred to the second effect via the evaporator re-circulation pump. The remaining effects operate in a similar manner. The condensate from each effect is pumped to the condensate header for use in preheating the feed. The last effect of the system operates near atmospheric pressure. The temperature of the evaporator brine from the 4th effect as it is transferred to the spray dryer is approximately 215°F.

In a multiple-effect evaporation system, a trade-off is made between the capital cost of the system (i.e., the number of effects) and the system's operating costs (primarily the net steam consumption). Thus, to optimize the number of effects in a multiple-effect evaporator, one must look to minimize the total annualized costs including both operating costs and the value of capital. If a capital recovery factor of zero is used, the analysis would favor the use of a large number of effects to minimize energy consumption which is the largest component of operating costs at the expense of higher capital investment. We do not believe this to be practical. During our analysis, we examined systems assuming a capital recovery factor between 10 and 20 percent.

The design constraints of the multiple-effect evaporator system were selected as follows:

- atmospheric discharge from the last effect;
- approximately 30 to 60°F temperature difference in each effect to maximize heat transfer and minimize heat transfer area;
- medium pressure steam from a packaged boiler (with a boiler combustion efficiency of 80%) to be used as source of steam supply;
- fuel gas available at $1.84 per MM Btu; and
- materials of construction chosen to be typical of those in seawater desalination systems. Available material of construction options, all nickel-based due to the presence of the chlorides in the solution, include copper-nickel, Monel and Inconel; Inconel 625 was chosen.

Prior to optimization, material and energy balances around the evaporator system were developed for each of the configurations, i.e., one, two, three or more effects, to calculate the amount of steam required and then determine the heat transfer area required to effect the evaporation. These

calculations result in the setting of the operational variables in each effect (temperature, pressure, duty distribution among effects and steam requirements). The heat transfer areas are calculated based on an overall heat transfer coefficient of 500 Btu/hr/sq ft/°F which is typical of seawater evaporation systems. No attempts were made in this study to conduct detailed heat transfer analysis of the system; the procedure is iterative in nature. It is important to note, however, that the boiling point rise in these solutions is negligible.

The results of the optimization calculation (Figure 3-7) indicate a minimum annualized cost to occur at 4 to 6 effects. For this study, a four-effect system was chosen as the design configuration.

The performance parameters for the four-effect system, as discussed above, were calculated and are summarized below:

Effect	Solution Flow Rate (lbs/hr Input	Output	Temperature Difference (°F)	Operating Pressure (psia)
1	80,000	64,177	62	80
2	64,177	48,143	32	50
3	48,143	32,525	32	30
4	32,525	17,780	32	15

The pumping requirements for the condensate return pumps and the evaporator recirculation pumps were calculated on the basis of the above flow rates and dynamic head requirements.

The feed preheater uses the combined condensate returns to preheat the feed to the evaporators to 180°F. The average temperature of the incoming condensate is approximately 260°F. The preheater requires a heat transfer area of approximately 700 sq ft.

Our process calculations show that 32,300 lbs of steam per hour is required to effect the evaporation of 62,220 lbs of water in the four-effect evaporator system. The steam rate, defined as lbs of water evaporated per lb of steam, is 1.93. In the ideal case, the steam rate is about 4 for a 4-effect evaporator. Heat losses through the insulation (approximately 10% per effect) accounts for a major portion of the reduction of steam efficiency. Steam consumed in preheating the feed accounts for the balance of this inefficiency.

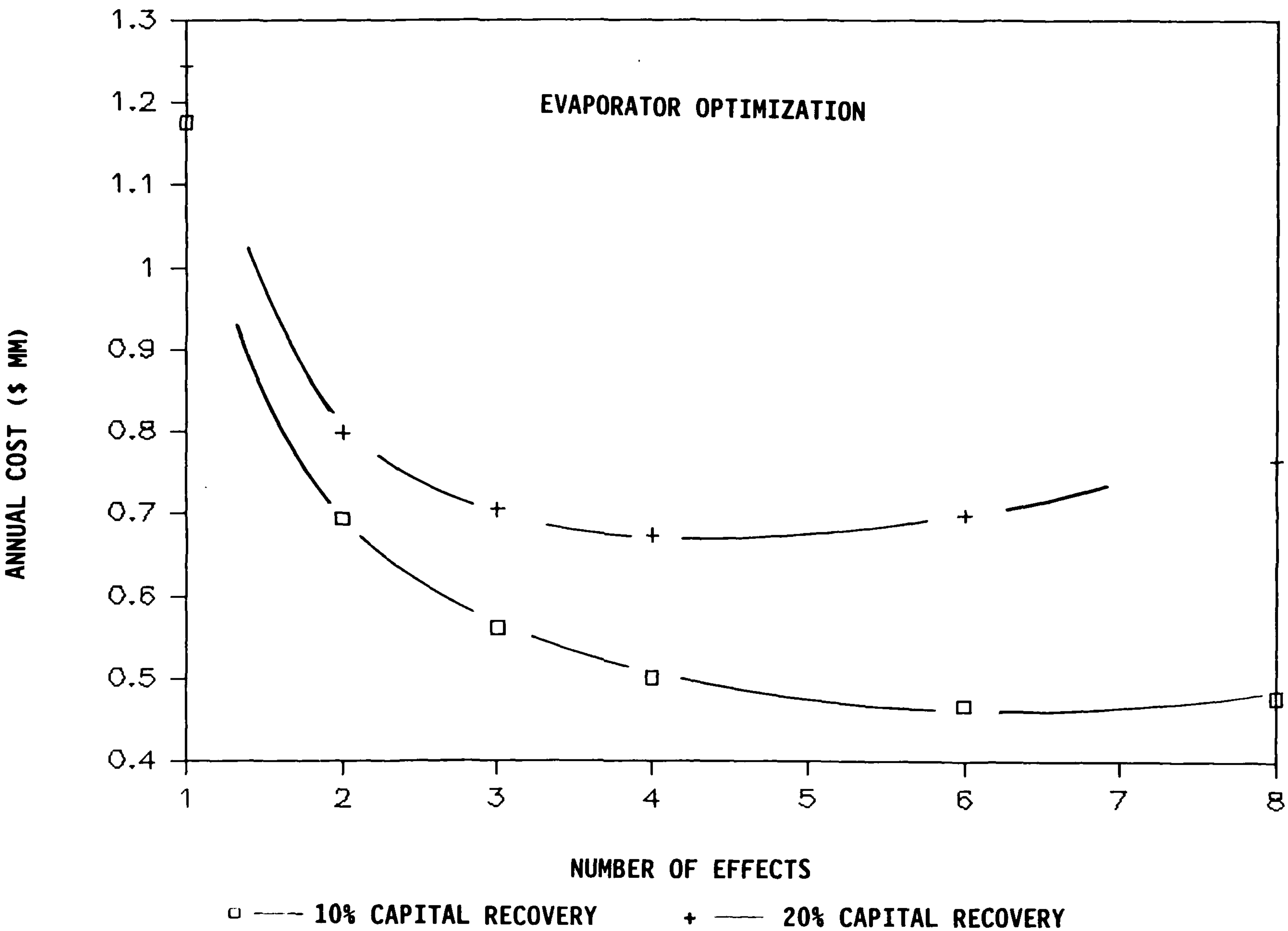
EVAPORATOR OPTIMIZATION
ANNUAL COST ($ MM)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
1
2
3
4
5
6
7
8
NUMBER OF EFFECTS
□ —— 10% CAPITAL RECOVERY
+ —— 20% CAPITAL RECOVERY

FIGURE 3-7

A natural-gas fired packaged boiler including a deaerator is provided in the design. It is conceivable that the evaporator condensate is of sufficient quality to be used as boiler feedwater.

Process options using mechanical vapor recompression (MVR) either as an add-on or an alternative to the four-effect evaporator were not explored in this study. Such options could reduce operating costs as MVR typically reduces energy requirements.

While the operating conditions are essentially the same, the evaporation duty for Case II is approximately 10% higher than that of Case I. It is the result of having a similar feed solution flow rate at a drastically reduced salt content and having to still achieve the same brine concentration.

3.2.5 Spray Dryer System (System 500)

The spray dryer system consists of a combustion unit, feed pump, centrifugal atomizer, drying chamber, cyclone separator with rotary valve for discharging dried salts, main blower and dust control equipment. The system also includes a tube conveyor, a dried-salt storage bin and a drumming station. Figure 3-8 presents a process flow diagram of the spray dryer system.

Process calculations for the spray dryer are included in Appendix B as Tables B-4 and B-5 for Case I and Case II, respectively. The spray dryer in Case I processes 422,430 lbs of brine per day and produces 42,240 lbs of dried salts per day. The process duty for the Case II spray dryer is about 20% of Case I.

Hot flue gas at 1000°F produced by the direct combustion of natural gas with an excess of air is used for the contact drying of the brine solution in the drying chamber. The brine solution from the evaporator system at about 215°F is pumped to the top of the spray chamber by a gear pump. The brine flow is atomized into the drying chamber by a centrifugal atomizer and contacts the drying air in a co-current fashion. Dried salts are entrained in the air flow, separated in the cyclone and discharged to the tube conveyor via a rotary valve. The drying air leaving the cyclone separator at about 300°F is passed through a bag filter to remove fine particulate before being vented to the atmosphere.

The conveyor delivers dried salts into a storage bin sized to collect the quantity of salts produced in a 24-hour period. The drumming station which packs dried salts into 55-gallon drums is sized to drum the dried salts produced in a 24-hour period in one 8-hour shift.

The daily number of 55-gallon drums required to contain dried salts and spent carbon for off-site disposal is considerable: 230 drums for Case I and 45 drums for Case II (of which 3 drums are spent carbon in either case). This is partially due to the low packing density of the spray dried salts (25 lb/ft^3 for spray dried sodium chloride versus 60 to 80 lb/ft^3 for crystallized sodium chloride).

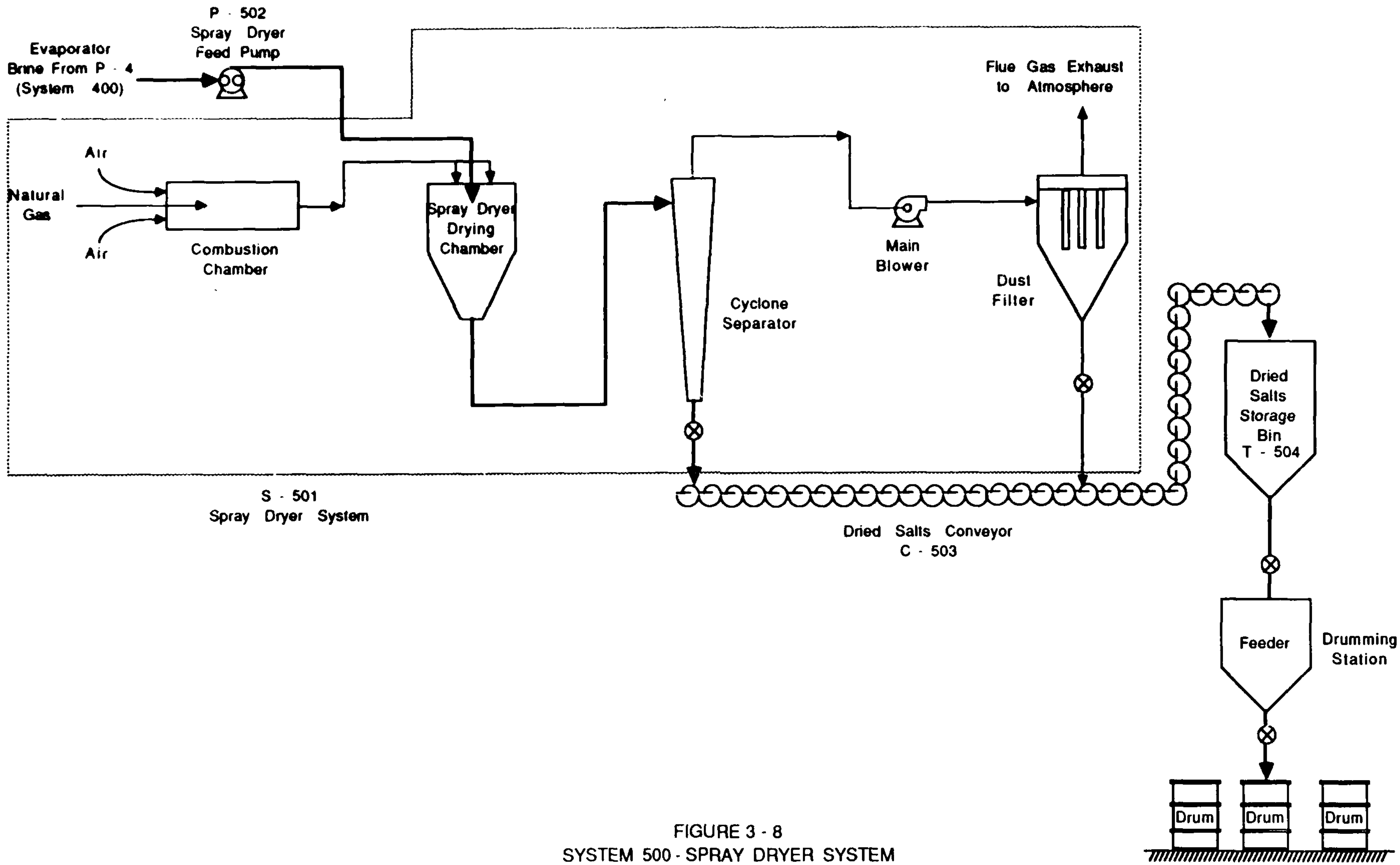

FIGURE 3 - 8
SYSTEM 500 - SPRAY DRYER SYSTEM

4.0 COST ESTIMATION AND ECONOMIC EVALUATION

4.1 Approaches to Cost Estimation

The preliminary process engineering analysis and equipment sizing performed on the NQ wastewater treatment system established the basis for estimating the capital investment and operating costs.

For component or subsystem costs, we used a combination of general published cost curves [1], a current cost estimation manual [2], and budgetary quotations from equipment suppliers. We used the Guthrie's Modular Factor method [3] to convert purchased component costs to installed costs. The modular factor, specific to each type of equipment, is intended to account for all direct and indirect cost elements in placing a piece of equipment into operation. These cost elements include engineering, procurement, freight, insurance, taxes, field installation (materials and labor), contractor's fee and contingency. The specific modular factors that were used along with an equipment list and the purchased component costs are shown in Tables A-1 and A-2, Equipment List and Cost - Case I and Case II respectively, Appendix A. All cost data were brought to current third Quarter, 1986 by using the Chemical Engineering Plant Cost Index.

Operating costs were developed based upon the operating requirements established in the mass balances and equipment sizing calculations as discussed in the previous section. Costs for operating materials were obtained from suppliers of such. Costs for labor and utilities were supplied by Sunflower AAP personnel.

4.2 Capital Investment

Capital investments for Case I and Case II, as summarized in Table 4-1, are $6.6 million and $4.6 million respectively. Major cost differences between Case I and Case II are in the areas of the cation exchange system and the spray dryer.

In addition to the process equipment, allowances are made to include plant building, offices and laboratory spaces, and equipment for offices and laboratories. A typical engineering fee (3% of the plant subtotal) and contingency (20% of the plant subtotal) are also included in the capital investments.

4.3 Operating Cost/Economic Evaluation

Operating costs of the Sunflower AAP wastewater treatment system using the GAC/IE technology options are shown in Tables 4-2 and 4-3 for Case I and Case II, respectively. The operating costs are grouped into two categories, variable costs and fixed costs. Variable costs include costs for utilities, regenerant chemicals, replacement of activated carbon and cation exchange resin, operating labor, and off-site disposal of potentially hazardous wastes. Fixed costs include items such as plant overhead, maintenance (materials, labor and supplies), depreciation, taxes and insurance. The basis for the cost evaluation, supplied by Sunflower AAP, is shown in Table 4-4.

TABLE 4-1

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
CAPITAL INVESTMENT SUMMARY - CASE I AND II

System Number	Description	Case I Installed Cost (1986 Dollars)	Case II Installed Cost (1986 Dollars)
100	Feed System	175,000	175,000
200	Carbon Adsorbers	243,000	243,000
300	Cation Exchangers	773,000	0
400	Multiple Effect Evaporator	2,251,000	2,331,000
500	Spray Dryer System	1,682,000	847,000
	TOTAL INSTALLED EQUIPMENT	$5,124,000	$3,596,000
Other	Plant Building	180,000	129,000
	Offices and Laboratories	25,000	25,000
	Office and Lab Equipment	20,000	20,000
	PLANT SUBTOTAL	$5,349,000	$3,770,000
	Engineering Fee (3% of Plant Subtotal)	160,000	113,000
	Contingency (20% of Plant Subtotal)	1,070,000	754,000
	TOTAL CAPITAL INVESTMENT	$6,579,000	$4,637,000

Source: Arthur D. Little, Inc.

TABLE 4-2

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
OPERATING COST SUMMARY - CASE I

Capital Investment: $6,579 Million (1986 Dollars)
Capacity: 200,000 Gallons per Day
Operation Basis: 8,760 Hours per Year

Description	Cost per Day (1986 Dollars)	Cost per Year (1986 Dollars)
VARIABLE COSTS		
Power	210	76,700
Fuel	2,310	843,200
Water	50	18,300
Carbon	750	273,800
Resin	170	62,100
NaCl	350	127,800
$Ca(NO_3)_2$	22,500	8,212,500
Unskilled Labor	798	291,200
Skilled Labor	798	291,200
Supervisory Labor	501	183,040
Off-Site Disposal	47,500	17,337,500
FIXED COSTS		
Plant Overhead (@119% of Total Labor)	2,500	910,900
Maintenance Materials, Labor and Supplies (4% of Capital Investment)	700	263,200
Depreciation (10% of Capital Investment)	1,800	657,900
Taxes and Insurance (@2% of Capital Investment)	400	131,600
TOTAL COSTS	$81,337	$29,681,000

Source: Arthur D. Little, Inc.

TABLE 4-3

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
OPERATING COST SUMMARY - CASE II

Capital Investment: $4,637 Million (1986 Dollars)
Capacity: 200,000 Gallons per Day
Operation Basis: 8,760 Hours per Year

Description	Cost per Day (1986 Dollars)	Cost per Year (1986 Dollars)
VARIABLE COSTS		
Power	130	47,500
Fuel	1,740	635,100
Water	50	18,300
Carbon	750	273,800
Resin	0	0
NaCl	0	0
$Ca(NO_3)_2$	0	0
Unskilled Labor	399	145,600
Skilled Labor	798	291,200
Supervisory Labor	501	183,040
Off-Site Disposal	10,600	3,869,000
FIXED COSTS		
Plant Overhead (@119% of Total Labor)	2,000	737,600
Maintenance Materials, Labor and Supplies (4% of Capital Investment)	500	185,500
Depreciation (10% of Capital Investment)	1,300	463,700
Taxes and Insurance (@2% of Capital Investment)	300	92,700
TOTAL COSTS	$19,068	$6,943,000

Source: Arthur D. Little, Inc.

TABLE 4-4

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
BASIS FOR COST EVALUATION

Item	Unit Cost
Direct Labor (DL), $/hr	17.50
Supervision (S), $/hr	22.00
Overhead, % of DL&S	119.00
Electricity, cents/kWh	5.00
Fuel Gas, $/MMBtu	1.84
Process Water, $/1,000 gals	0.89
Hazardous Waste Disposal, $/55-gal Drum	200.00

Source: Sunflower AAP

The total annual cost for Case I is approximately $30 million with nearly 60% attributed to off-site disposal, 30% for chemical supplies and about 3 1/2% for capital-related fixed cost items.

Daily consumption of utilities and chemicals for Case I are shown in Table 4-5. The cation resin life is assumed to be 3000 cycles. The price of sodium chloride is based on bulk shipment of rock salt (medium or coarse grade). The price of calcium nitrate is based on bulk shipment of calcium nitrate solution at 30 wt % (available form W.R. Grace & Co., Construction Products Division).

A manning summary for the plant operation (Case I) is shown in Table 4-6. We estimate that 2 operators and 2 general laborers are needed for the plant operation for each shift. Allowance for an engineer/supervisor is also made for supervising the system operation.

With the elimination of the cation exchange process step, the total annual cost of the system is reduced to $7 million for Case II. More than 55% of the total Case I operating cost (or $3.9 million per year) is still attributed to off-site disposal. Utility and chemical requirements for Case II are shown in Table 4-7. Please note the elimination of requirements for resin replacement and sodium chloride and calcium nitrate consumptions. The manning summary for Case II is shown in Table 4-8. A reduction of unskilled labor is realized for Case II because the preparation of regenerants is eliminated and there is a considerable reduction in the number of drums for disposal.

TABLE 4-5

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
UTILITIES AND CHEMICALS CONSUMPTION - CASE I

Material	Units	Daily Consumption	Cost ($/unit)	Cost ($/day)
Power	kWh	4,267	0.05	210
Fuel	MM Btu	1,255	1.84	2,310
Water	1,000 gal	101	0.50	50
Carbon	lbs	600	1.25	750
Resin	cu ft	2	75.90	170
NaCl	lbs	34,500	0.01	350
$Ca(NO_3)_2$	lbs	45,000	0.50	22,500
TOTAL				26,300

Source: Arthur D. Little, Inc.

TABLE 4-6

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
MANNING SUMMARY FOR PLANT OPERATION - CASE I

Type	Number	Man-hours/ Year	Unit Cost ($/hr)	Annual Cost ($/yr)
Unskilled	8	2,080	17.50	291,200
Skilled	8	2,080	17.50	291,200
Supervisory	4	2,080	22.00	183,040
TOTAL	20			$765,440

Source: Arthur D. Little, Inc.

TABLE 4-7

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
UTILITIES AND CHEMICALS CONSUMPTION - CASE II

Material	Units	Daily Consumption	Cost ($/unit)	Cost ($/day)
Power	kWh	2,675	0.05	130
Fuel	MM Btu	945	1.84	1,740
Water	1,000 gal	104	0.50	50
Carbon	lbs	600	1.25	750
Resin	cu ft	0	75.90	0
NaCl	lbs	0	0.01	0
$Ca(NO_3)_2$	lbs	0	0.50	0
TOTAL				2,700

Source: Arthur D. Little, Inc.

TABLE 4-8

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
MANNING SUMMARY FOR PLANT OPERATION - CASE II

Type	Number	Man-hours/ Year	Unit Cost ($/hr)	Annual Cost ($/yr)
Unskilled	4	2,080	17.50	145,600
Skilled	8	2,080	17.50	291,200
Supervisory	4	2,080	22.00	183,040
TOTAL	16			$619,840

Source: Arthur D. Little, Inc.

5.0 DISCUSSION AND CONCLUSIONS

The information presented above clearly indicates that without any front-end process modification, carbon adsorption/cation exchange/multiple-effect evaporation/spray drying (Case I process scheme) for treating the NQ wastewater from SAC and SAR lagoons is questionable at best. As we indicated in our Task 3 (Subtask 3.7) Draft Final Report[4], of the five wastewater streams tested, the combined SAR/SAC lagoon wastewater was the least suitable stream for using the carbon adsorption/ion exchange treatment technology. The primary reasons for this unsuitability are as follows:

1) The combined SAC/SAR wastewater is too highly concentrated in competing cations (Na and Ca) which ultimately reduce the effectiveness of the cation resin in its removal of Gu and NH_3-N ions; and

2) The combined SAC/SAR wastewater is already too highly concentrated in anions (sulfates and nitrates) to achieve any further concentration and volume reduction.

However, it is still possible to achieve certain process improvement in the carbon adsorption/ion exchange system with the following front-end process modifications:

- chill the wastewater prior to or in lieu of lime/steam sparging for controlling NQ so as to allow for the recovery/reuse of NQ and the reduction in Ca loading to cation bed and NO_3-N loading to evaporation/spray drying system;

- improve control of lime/steam sparging operation (if operation still deemed necessary) to control Ca loading to cation bed;

- improve performance of sulfuric and nitric acid process recovery units to reduce acid losses and thereby reduce SO_4 and NO_3-N loadings to the evaporator/spray drying system; and

- identify and eliminate, if possible, the source of Na (NaOH in Sump A-9042) to reduce Na loading to cation bed.

Based on the results of the two cases evaluated, however, it is evident that Case II offers a significant reduction in both capital and operating costs. The capital cost of the wastewater treatment system proposed in Case II ($4.6 million) is approximately 70% that of Case I; while the annual operating cost (including depreciation, taxes and insurance) for Case II ($6.9 million) is only 23% that of Case I ($30 million).

The cost advantages (both capital and operating) come about as a result of the elimination of the cation exchange unit. Due to the fact there are considerable quantities of Na and Ca ions in the wastewater to be treated, the cation resin becomes overwhelmed with these two competing cations and, therefore, very little of the resin is available for removing the cations of concern, i.e., Gu and NH_3-N. As a result, the resin needs to be

regenerated at frequent intervals, requiring the use of large quantities of calcium nitrate and sodium chloride regenerant solutions.

In addition, the spent sodium chloride regenerant, which will be primarily calcium chloride ($CaCl_2$), is assumed to require drying for ultimate disposal. This large quantity of salt results in the generation of a considerable number of drums to be landfilled off-site as a hazardous waste.

Of the two process schemes evaluated, Case II (without cation exchange) offers distinct cost advantages over Case I (with cation exchange). This conclusion would in all probability continue to remain valid even if one allows credit for the guanidinium and ammonium nitrate recovery/recycle in Case I. At the present time, our cost analysis has taken no credit for this recycle.

If the basic process schemes studied in this task are in the competitive range of other process technologies being examined in parallel by Sunflower AAP, it may be beneficial to attempt to further optimize the Case II System design and, therefore, its process economics. These improvements may come about as a result of:

1) increasing the brine concentration in the evaporator bottoms;

2) adding mechanical compaction devices to increase the packing density of the spray dried salts; and/or

3) using a crystallizer/drum dryer system in place of an evaporator/spray dryer system.

The concentration of the brine discharging from the evaporator impacts strongly on the capacity requirement of the downstream spray dryer. We have conservatively selected the 10 wt % as the evaporator brine concentration primarily because the interactions of ions in that stream are not fully understood at this time. With a limited number of laboratory tests on a simulated feed to determine the salting-out concentrations, it is likely that one could increase the brine concentration leaving the evaporator which would slightly increase the evaporator area requirement but more importantly, reduce the spray dryer size.

Owing to the nature of the process, products from spray dryers are generally low in bulk density. The salt packing density of the spray-dried salts is assumed to be 25 lbs/ft^3, based on our discussions with spray dryer manufacturers. The quantity of drums may be reduced by 30 to 50% if the salts exiting the spray dryer are mechanically compacted prior to drumming.

A limited pilot-scale testing on a simulated spray dryer feed is also required to optimize the operating conditions, and characterize the spray dried product prior to the final design of the spray dryer system. This testing should be conducted by a competent spray dryer manufacturer.

Alternatively, it is conceivable that the multiple-effect evaporator/spray dryer scheme can be replaced by a crystallizer/drum dryer scheme; the

crystallizer would generate salt crystals thereby producing higher density salts. The wet salt crystals would then be dried in a drum dryer prior to packaging into 55-gal drums for off-site disposal. The higher density salts would ultimately reduce the number of drums requiring off-site disposal and, therefore, reduce disposal costs.

REFERENCES

(1) R.S. Hall, J. Matley and K.J. McHaughton, Chemical Engineering, April 5, 1982, pp. 80-116.

(2) Richardson Process Plant Estimation Standards, Richardson Engineering Services, Inc. 1985 Edition.

(3) K.M. Guthrie, Chemical Engineering, March 24, 1969, pp. 114-116.

(4) Draft final Report on Sunflower AAP NQ Wastewater Treatment GAC/IE Pilot Plant, Contract No. DAAK11-85-D-0008, to USATHAMA by Arthur D. Little, Inc., September 30, 1986.

APPENDIX A

EQUIPMENT LIST AND COST

- Table A-1 - Case I
- Table A-2 - Case II

TABLE A - 1

EQUIPMENT LIST AND COST - CASE I

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 100 - FEED SYSTEM					
F-101	Feed Strainers	500	2	1,000	1.21	1,210
P-102	Feed Transfer Pumps and Filters 70 gpm, 80' TDH, 3 HP TEFC motor; rubber lined pump and filter housing; PP filter elements.	3,615	2	7,230	3.38	24,437
T-103	Feed Surge Tanks 24000 gal capacity, flat bottom vertical, fiberglass.	28,000	2	56,000	1.96	109,760
P-104	Feed Charging Pumps and Filters 140 gpm, 40' TDH, 5 HP TEFC motor; rubber lined pump, filter and piping; two required, one as installed spare.	5,925	2	11,850	3.38	40,053
	SYSTEM 100 SUBTOTAL			$76,080		$175,460

TABLE A - 1 (continued)

EQUIPMENT LIST AND COST - CASE I

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 200 - CARBON ADSORBERS					
S-201	Carbon Adsorption System Two Adsorbers piped with manual flow directional valves; 4' dia, 8' straight side length; 3000 lbs activated carbon in each adsorber; carbon steel vessel coated with epoxy lining (12 mil); PVC piping and ball valves; 5-day on-stream time; non-regenerable.	60,000	1	60,000	2.26	135,600
I-202	Initial Charge of Activated Carbon Calgon Filtrasorb 300, 6400 lbs total. $1.25 per lb delivered.	1.25	6400	8,000	1.1	8,800
S-203	Carbon Slurrying System 190 lb/min carbon capacity; System includes bulk bin, eductor, water pump and piping; 2 hrs over 5 days; rubber lined steel construction, 5 HP.	9,000	1	9,000	2.26	20,340
S-204	Spent Carbon Dewatering System 1000 lb/hr capacity.	9,000	1	9,000	2.26	20,340
C-205	Compressed Air Station Compressed air to supply motive force to displace spent carbon from adsorbers and to operate control valves; package consists of a 100 SCFM non-lubricated two-stage air-cooled compressor, 30 HP motor, 125 gal air receiver.	20,200	1	20,200	2.08	42,016
D-206	Desiccant Air Dryer Heatless dryer packed with activated alumina to produce 100 SCFM of -40 oF dew point air at 100 psig.	7,050	1	7,050	2.26	15,933
	SYSTEM 200 SUBTOTAL			$113,250		$243,029

TABLE A - 1 (continued)

EQUIPMENT LIST AND COST - CASE I

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 300 - CATION EXCHANGE SYSTEM					
S-301	Cation Exchanger System Two ion exchanger beds operated in parallel; each bed holds 420 cubic ft of cation exchange resin, 10' dia, 9' straight side length; vessels are lined baked phenolic resin; 2" piping; PVC piping system with automatic valves; system operation controlled by adjustable timer; each resin bed is designed to be on stream for 8 hours before regeneration.	180,000	1	180,000	2.26	406,800
I-302	Initial Charge of Cation Resin Amberlite IR-120, 826 cubic ft total. $75.90 per cubic ft delivered.	76	826	62,693	1.1	68,963
P-303	Calcium Nitrate Unloading Pump 75 gpm, 200' TDH; centrifugal; cast iron, 10 HP TEFC motor; sized to unload 18,000 gal railroad tanker of 30% wt soln. in 4 hours.	2,700	1	2,700	3.38	9,126
T-304	Calcium Nitrate Concentrate Storage Tank 30,000 gal capacity, flat bottom, 15' diameter, 24' height, carbon steel.	32,600	1	32,600	2.55	83,130
P-305	Calcium Nitrate Concentrate Pump 40 gpm, 80' TDH; centrifugal; cast iron, 3 HP drip-proof motor; operates 4 hrs every 8 hrs.	1,050	1	1,050	3.38	3,549
P-306	Calcium Nitrate Regenerant Dilution Pump 100 gpm of condensate to dilute 30% calcium nitrate solution into 10% for regenerating the cation bed; 80' TDH; cast iron, 5 HP drip-proof motor; operates 4 hrs every 8 hrs.	1,100	1	1,100	3.38	3,718
S-307	Crystal Salt Unloading System Tube conveyor, 4" disks and tube, 200' total chain and tube length, carbon steel construction, 1 HP motor drive, complete with inlet section, inspection port, 2 discharge gates. Sized to convey up to 6000 lb/hr of salt crystals into any one of the two salt solution tanks.	19,000	1	19,000	2.1	39,900
S-308	Salt Unloading Pit 8 x 15 x 5' deep concret pit, epoxy coated, with steel truck ramp; sized for one truck load or 40,000 lbs.	10,000	1	10,000	1	10,000

TABLE A - 1 (continued)

EQUIPMENT LIST AND COST - CASE I

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
T-309	Salt Solution Tanks 10,000 gal capacity, open top, flat bottom, epoxy coated carbon steel. Each tank is sized to hold one day requirement of salt solution at 36% saturation concentration at 60 F.	18,000	2	36,000	2.55	91,800
P-310	Sodium Chloride Concentrate Pump 40 gpm of 36% salt soln., 50' TDH, centrifugal, wetted parts are glass-filled epoxy plastic; 2 HP TEFC motor. Operates 2 hrs every 8 hrs.	1,100	1	1,100	3.38	3,718
P-311	Salt Solution Make-up Pump 40 gpm of water, 50' TDH, centrifugal, cast iron, 2 HP drip-proof motor. Operates 2 hrs every 8 hrs.	1,050	1	1,050	3.38	3,549
P-312	Sodium Chloride Regerant Dilution Pump 103 gpm of water, 50' TDH, centrifugal, cast iron, 3 HP drip-proof motor. Operates 2 hrs every 8 hrs.	1,100	1	1,100	3.38	3,718
P-313	Backwash Flow Pump 300 gpm of filtered feed wastewater, 100' TDH, centrifugal, rubber-lined pump and filter, PVC piping, 10 HP motor. Operates 1 hr every 8 hrs.	12,000	1	12,000	3.38	40,560
P-314	Rinse Water Pump 140 gpm of evaporrtor condensate, 100' TDH, centrifugal, cast iron, 7.5 HP drip-proof motor. Operates 1 hr every 8 hrs.	1,400	1	1,400	3.38	4,732
	SYSTEM 300 SUBTOTAL			$361,793		$773,263

TABLE A - 1 (continued)

EQUIPMENT LIST AND COST - CASE I

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 400 - MULTIPLE EFFECT EVAPORATOR					
E-401	Four-Effect Evaporator; sized at 900 sq ft per effect; last effect discharges at atmospheric pressure; first effect designed for 80 psia, 2nd at 50 psia, 3rd at 30 psia and fourth effect is atmospheric; Inconel 625 used for all solution contacted materials. System designed to handle 80,000 lbs per hour of solution from cation exchange--System 300; system requires 32300 lbs per hour of steam at 180 psia.	690,000	1	690,000	1.9	1,311,000
E-402	Feed Preheater; 660 sq ft of area used to preheat feed from 60 F to 180 F; design pressure of 150 psi; shell and tube type design; tube materials are Inconel 625; shell side is carbon steel.	28,000	1	28,000	3.29	92,120
P-403	Feed Transfer Pump (P-400); 200 gpm, 250' TDH discharge, 20 HP; Inconel 625.	6,300	1	6,300	3.38	21,294
P-404	Condensate Return Pump; 2 req'd; 50 gpm, 125'TDH, 3 HP; carbon steel.	1,250	2	2,500	3.38	8,450
P-405	Condensate Return Pump; 2 req'd; 50 gpm, 250'TDH, 10 HP; carbon steel.	1,700	2	3,400	3.38	11,492
T-406	Condensate Surge Tank for preheater; 1000 gal capacity, 75 psi design pressure; carbon steel; receives condensate from all effects.	6,100	1	6,100	2.55	15,555
B-407	Packaged Boiler designed to deliver 32,300 lbs of sat. steam per hour at 180 psia.	190,500	1	190,500	2.83	539,115
T-408	Condensate Storage Tanks 30,000 gal, open top, flat bottom, carbon steel construction; sized to hold evaporator condensate for 4 hrs before discharge. Two required.	36,000	2	72,000	2.55	183,600

TABLE A - 1 (continued)

EQUIPMENT LIST AND COST - CASE I

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
P-409	Condensate Discharge Pump; 150 gpm, 100' TDH, 7.5 HP; carbon steel.	1,540	1	1,540	3.38	5,205
P-410	Evaporator Feed Recirculation Pump; 150 gpm, 250' TDH, 20 HP; Inconel 625.	5,765	1	5,765	3.38	19,486
P-411	Evaporator Feed Recirculation Pump; 100 gpm, 150' TDH, 7.5 HP; Inconel 625.	3,664	1	3,664	3.38	12,384
P-412	Evaporator Feed Recirculation Pump; 75 gpm, 100' TDH, 5 HP; Inconel 625.	3,524	1	3,524	3.38	11,911
P-413	Evaporator Feed Recirculation Pump; 50 gpm, 100' TDH, 3 HP; Inconel 625.	3,303	1	3,303	3.38	11,164
P-414	Preheater Condensate Pump; 150 gpm, 250' TDH, 20 HP; carbon steel.	2,515	1	2,515	3.38	8,501
	SYSTEM 400 SUBTOTAL			$1,019,111		$2,251,277

TABLE A - 1 (continued)

EQUIPMENT LIST AND COST - CASE I

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 500 - SPRAY DRYER SYSTEM					
S-501	Spray Dryer System Co-current flow spray dryer with centrifugal atomizer, SS 304L. Design feed rate: 422,430 lb/day of evaporator brine at 10 wt.% and 215 oF. System consists of gas-fired burner, atomizer with driver, drying chamber, exhaust blower, cyclone and rotary discharge valve, dust control system and duct work. Insulated and weather-proofed for outdoors installation. 30' drying chamber diameter, approx. 40' high; 20 MM Btu/hr fuel requirement; 15,841 lb/hr of water removal. 100 HP TEFC blower motor, 2 HP atomizer driver.	700,000	1	700,000	2.26	1,582,000
P-502	Spray Dryer Feed Pump Gear pump, 35 gpm of 10% brine, 75'TDH, Incoloy construction, 5 HP TEFC motor.	2,900	1	2,900	3.38	9,802
S-503	Dried Salt Conveyor Tube Conveyor, 4" disks and tube, carbon steel construction, system complete with driver box, chains and disk, inlet section, inspection port, one discharge gate; sized for 150' tube length, 3 HP driver motor, continuous operation. Sized for 42,500 lb/hr of dried salts with 25 lb/cubic ft density.	17,500	1	17,500	2.10	36,750
T-504	Dried Salt Storage Bin 2000 cubic feet volume, epoxy coated steel, conical bottom with motor driven rotary valve and discharge hose. Sized to drum 42,243 lb of dried mixed salts per day during the day shift. 231 55-gal drums per day. 0.5 HP TEFC motor for the feeder. Operates 8 hrs per day.	28,000	1	28,000	1.90	53,200
	SYSTEM 500 SUBTOTAL			$748,400		$1,681,752

TABLE A - 2

EQUIPMENT LIST AND COST - CASE II

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 100 - FEED SYSTEM					
F-101	Feed Strainers	500	2	1,000	1.21	1,210
P-102	Feed Transfer Pumps and Filters 70 gpm, 80' TDH, 3 HP TEFC motor; rubber lined pump and filter housing; PP filter elements.	3,615	2	7,230	3.38	24,437
T-103	Feed Surge Tanks 24000 gal capacity, flat bottom vertical, fiberglass.	28,000	2	56,000	1.96	109,760
P-104	Feed Charging Pumps and Filters 140 gpm, 40' TDH, 5 HP TEFC motor; rubber lined pump, filter and piping; two required, one as installed spare.	5,925	2	11,850	3.38	40,053
	SYSTEM 100 SUBTOTAL			$76,080		$175,460

TABLE A - 2 (continued)

EQUIPMENT LIST AND COST - CASE II

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 200 - CARBON ADSORBERS					
S-201	Carbon Adsorption System Two Adsorbers piped with manual flow directional valves; 4' dia, 8' straight side length; 3000 lbs activated carbon in each adsorber; carbon steel vessel coated with epoxy lining (12 mil); PVC piping and ball valves; 5-day on-stream time; non-regenerable.	60,000	1	60,000	2.26	135,600
I-202	Initial Charge of Activated Carbon Calgon Filtrasorb 300, 6400 lbs total. $1.25 per lb delivered.	1.25	6400	8,000	1.1	8,800
S-203	Carbon Slurrying System 190 lb/min carbon capacity; System includes bulk bin, eductor, water pump and piping; 2 hrs over 5 days; rubber lined steel construction, 5 HP.	9,000	1	9,000	2.26	20,340
S-204	Spent Carbon Dewatering System 1000 lb/hr capacity.	9,000	1	9,000	2.26	20,340
C-205	Compressed Air Station Compressed air to supply motive force to displace spent carbon from adsorbers and to operate control valves; package consists of a 100 SCFM non-lubricated two-stage air-cooled compressor, 30 HP motor, 125 gal air receiver.	20,200	1	20,200	2.08	42,016
D-206	Desiccant Air Dryer Heatless dryer packed with activated alumina to produce 100 SCFM of -40 oF dew point air at 100 psig.	7,050	1	7,050	2.26	15,933
	SYSTEM 200 SUBTOTAL			$113,250		$243,029

TABLE A - 2 (continued)

EQUIPMENT LIST AND COST - CASE II

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 300 - CATION EXCHANGE SYSTEM *(not required in Case II)*					
	SYSTEM 300 SUBTOTAL			$0		$0

TABLE A - 2 (continued)

EQUIPMENT LIST AND COST - CASE II

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 400 - MULTIPLE EFFECT EVAPORATOR					
E-401	Four-Effect Evaporator; sized at 1000 sq ft per effect; last effect discharges at atmospheric pressure; first effect designed for 80 psia, 2nd at 50 psia, 3rd at 30 psia and fourth effect is atmospheric; Inconel 625 used for all solution contacted materials. System designed to handle 70,000 lbs per hour of solution from cation exchange--System 300; system requires 35530 lbs per hour of steam at 180 psia.	737,000	1	737,000	1.9	1,400,300
E-402	Feed Preheater; 560 sq ft of area used to preheat feed from 60 F to 180 F; design pressure of 150 psi; shell and tube type design; tube materials are Inconel 625; shell side is carbon steel.	25,200	1	25,200	3.29	82,908
P-403	Feed Transfer Pump; 200 GPM, 250' TDH discharge, 20 HP; Inconel 625.	6,300	1	6,300	3.38	21,294
P-404	Condensate Return Pump; 2 req'd; 50 GPM, 125' TDH, 3 HP; carbon steel.	1,250	2	2,500	3.38	8,450
P-405	Condensate Return Pump; 2 req'd; 50 GPM, 250 'TDH, 10 HP; carbon steel.	1,700	2	3,400	3.38	11,492
T-406	Condensate Surge Tank for preheater; 1000 gal capacity, 75 psi design pressure; carbon steel; receives condensate from all effects.	6,100	1	6,100	2.55	15,555
B-407	Packaged Boiler; designed to deliver 35,300 lbs of sat. steam per hour at 180 psia.	190,500	1	190,500	2.83	539,115
T-408	Condensate Storage Tanks 30,000 gal, open top, flat bottom, carbon steel construction; sized to hold evaporator condensate for 4 hrs before discharge. Two required.	36,000	2	72,000	2.55	183,600

TABLE A - 2 (continued)

EQUIPMENT LIST AND COST - CASE II

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
P-409	Condensate Discharge Pump; 150 gpm, 100' TDH, 7.5 HP; carbon steel.	1,540	1	1,540	3.38	5,205
P-410	Evaporator Feed Recirculation Pump; 150 gpm, 250' TDH, 20 HP; Inconel 625.	5,765	1	5,765	3.38	19,486
P-411	Evaporator Feed Recirculation Pump; 100 gpm, 150' TDH, 7.5 HP; Inconel 625.	3,664	1	3,664	3.38	12,384
P-412	Evaporator Feed Recirculation Pump; 75 gpm, 100' TDH, 5 HP; Inconel 625.	3,524	1	3,524	3.38	11,911
P-413	Evaporator Feed Recirculation Pump; 50 gpm, 100' TDH, 3 HP; Inconel 625.	3303	1	3,303	3.38	11,164
P-414	Preheater Condensate Pump; 150 gpm, 250' TDH, 20 HP; carbon steel.	2515	1	2,515	3.38	8,501
	SYSTEM 400 SUBTOTAL			$1,063,311		$2,331,365

TABLE A - 2 (continued)

EQUIPMENT LIST AND COST - CASE II

ITEM	DESCRIPTION	UNIT COST	NO. OF UNITS	TOTAL COST	MODULAR FACTOR	INSTALLED COST
	SYSTEM 500 - SPRAY DRYER SYSTEM					
S-501	Spray Dryer System Co-current flow spray dryer with centrifugal atomizer, SS 304L. Design feed rate: 82,900 lb/day of evaporator brine at 10 wt.% and 215 oF. System consists of gas-fired burner, atomizer with driver, drying chamber, exhaust blower, cyclone and rotary discharge valve, dust control system and duct work. Insulated and weather-proofed for outdoors installation. 17' drying chamber diameter, approx. 22' high; 4.0 MM Btu/hr fuel requirement; 3,259 lb/hr of water removal. 25 HP TEFC fan blower motor, 0.5 HP atomizer driver.	348,000	1	348,000	2.26	786,480
P-502	Spray Dryer Feed Pump Gear pump, 7.5 gpm of 10% brine, 75'TDH, Incoloy construction, 1 HP TEFC motor.	1,600	1	1,600	3.38	5,408
S-503	Dried Salt Conveyor Tube Conveyor, 4" disks and tube, carbon steel construction, system complete with driver box, chains and disk, inlet section, inspection port, one discharge gate; sized for 150' tube length, 3 HP driver motor, continuous operation. Sized for 362 lb/hr of dried salts with 25 lb/cubic ft density.	17,500	1	17,500	2.10	36,750
T-504	Dried Salt Storage Bin 500 cubic feet volume, epoxy coated steel, conical bottom with motor driven rotary valve and discharge hose. Sized to drum 8,690 lb of dried mixed salts per day during the day shift. 47 55-gal drums per day. 0.5 HP TEFC motor for the feeder. Operates 8 hrs per day.	9,500	1	9,500	1.90	18,050
	SYSTEM 500 SUBTOTAL			$376,600		$846,688

APPENDIX B

DESIGN CALCULATIONS

- Table B-1 - Carbon Bed Sizing
- Table B-2 - Cation Exchange Bed Sizing
- Table B-3 - Cation Exchange Bed Regeneration Requirements
- Table B-4 - Spray Dryer Process Calculations - Case I
- Table B-5 - Spray Dryer Process Calculations - Case II

TABLE B-1

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
CARBON BED SIZING CALCULATIONS

Stream:	Combined SAR and SAC Streams	
Flow Rate:		
gal/day	200,000	
gal/min	138.9	
Operating Temp., °F:	65	
Carbon Consumption:		
lb of carbon/day	574	
Carbon Type:	Granular Activated Carbon	
Carbon Grade:	Calgon Filtrasorb 300	
Bed Density, Backwashed and Drained, lbs/cu ft:	30	
Contact Time Requirement:		
cu ft carbon/gpm	0.4	(from Pilot Plant Data)
	0.73	(Design Basis)
Carbon Bed Size:		
cu ft of carbon	101	
lbs of carbon	3,042	
Design Bed Expansion:	0	(not required)
Backwash Velocity, gpm/sq ft:	19	(from Calgon Bulletin 20-2d)
Delta P/ft of bed, inches of water:	10	(Backwash; from Chart)
Vessel Configuration, L/D:	2	
Diameter, ft:	4.01	
Length, ft:	8.02	
On Stream Time, days:	5.3	
Backwash Flow Rate, gpm:	60	(if required)
Flow Direction:		
Adsorption	Downflow	
Backwash	Upflow	(if required)
Adsorption Flow, gpm/sq ft:	10.99	
Delta P/ft of Bed, inches water:	6	(Adsorption; from Chart)
Pressure Drop, psi:		
Adsorption	1.74	
Backwash	2.89	(if required)

TABLE B-2

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
ION EXCHANGE SYSTEM SIZING CALCULATIONS

Stream: Combined SAR and SAC Streams
Type: Cation Exchange
Resin Grade: Amberlite IR-120

Flow Rate:				
gal/day	200,000	200,000	200,000	200,000
gal/min	138.9	138.9	138.9	138.9
Design Option No.	IX-01	IX-02	IX-03	IX-04
Design Criteria:				
Breakthrough Volume	23	23	23	23
Flow Velocity, gpm/sq ft				
Feed	5.0	5.0	5.0	5.0
Backwash	10.0	5.6	5.6	5.6
Regenerant	2.0	2.0	2.0	2.0
Rinse	5.0	5.0	5.0	5.0
Design Operating Temp., °F	70.0	70.0	70.0	70.0
Min. Column Area, sq ft	27.8	27.8	27.8	27.8
Min. Column Dia., ft	5.9	5.9	5.9	5.9
Specified Col. Dia., ft	6.0	6.0	6.0	6.0
Column Flow Area, sq ft	28.3	28.3	28.3	78.5
Bed Volume, cu ft/hr	48.4	48.4	48.4	48.4
Bed Expansion Ratio	1.9	1.5	1.5	1.5
Vessel Volume, cu ft/hr	92.0	72.6	72.6	72.6
Overall L/D Ratio	5.0	4.0	3.5	0.8
Max. Vessel Length, ft	30.0	24.0	21.0	8.0
Vessel Volume, cu ft	848.2	678.6	593.8	628.3
Resin Volume, cu ft/bed	446.44	452.39	395.84	418.88
On Stream Time, hr				
1 Bed	9.2	9.3	8.2	8.6
2 Beds	18.4	18.7	16.3	17.3
3 Beds	27.7	28.0	24.5	25.9
4 Beds	36.9	37.4	32.7	34.6

Selected Design: Design Option No. IX-04
Number of Resin Beds - 1 On-Stream
1 Regen
Vessel Size - 10 ft Dia., 8 ft Height
On-Stream Time - 8 Hours

TABLE B-3

SUNFLOWER AAP NQ WASTEWATER TREATMENT SYSTEM
CATION REGENERATION SYSTEM SIZING

Cation Resin Volume, cu ft:	419
Cation IX Vessel Volume, cu ft:	628.3
Design On-Stream Time, hrs:	8

Regenerant Requirements:	$Ca(NO_3)_2$	NaCl	Water
Concentration, wt%:	10	15	100
Bed Volume	5.4	2.7	1.7
Solution Required, gal/cycle: (Note 1)	16927	8463	10029
Solution Sp. Gr.:	1.08	1.1	1.0
Storage Volume, gal/day	50780	25390	30087
Salt Required, lbs/cycle:	15230	11634	0
lbs/day:	45689	34901	0
Regenerant Storage Requirement: (Notes 2 & 3)			
Storage Tank Volume, gal:	50000	40000	116882
L/D:	1.06	1.16	0.73
Tank Diameter, ft:	20.0	18.0	30.1
Tank Height, ft:	21.2	20.9	22.0
Regenerant Pumping Requirement:			
Flow Velocity, gpm/sq ft:	2	2	5
Flow Area, sq ft:	78.5	78.5	78.5
Max. Flow Rate, gpm:	157	157	393
Specified Flow Rate, gpm:	140	140	300
Pump-On Time, hrs:	2.02	1.01	0.56
Calculated Flow Velocity, gpm/sq ft:	1.78	1.78	3.82
Pressure Drop, psi/ft of bed:	0.18	0.18	0.35
psi/bed:	0.96	0.96	1.87
Pressure Drop Allowance for Piping, psi:	2	2	5
Pump Head Required, psi:	3.0	3.0	6.9

Note 1: Rinse water required is calculated based on the required bed volumes plus one vessel volume.

Note 2: Sufficient storage for one day operation; preparation of solution during day-shift only.

Note 3: Evaporator condensate from condensate hold tank is used for preparing regeneration solution and rinse.

TABLE B-4

SPRAY DRYER PROCESS CALCULATIONS - CASE I

1. DESIGN BASIS:

Brine Flow from Multiple Effect Evaporator, lb/day:	422,430
Sale Concentration, % wt:	10
Brine Temperature, °F:	215
Total Water Removal, lb/hr:	15,841

2. COMBUSTION AIR REQUIREMENT:

Assumed Fuel Type:	Natural Gas
HHV, Btu/SCF:	1,015
Btu/lb of Methane:	23,879
Specific Heating Value, lb/MMBtu:	41.88
Stoichiometric Combustion:	

	/lb Fuel	/MMBtu	Cp
Combustion Air Requirement, lb:			
O_2	3.99	167.09	
N_2	13.28	556.14	
TOTAL	17.27	723.23	
Specific Heat of Air, Cp1, Btu/°F, lb:			0.262
Combustion Products:			
CO_2	2.74	114.75	0.28
H_2O	2.25	94.23	1.51
N_2	13.28	556.14	0.27
TOTAL PRODUCTS	18.27	765.11	
Sp. Ht. of Combustion Products, Cp2, Btu/°F, lb:			0.42
Molecular Weight:	29.17		
Flame Temperature, T2, °F:	3,551		
Assumed Ambient Temperature, T1, °F:	40		
Specified Drying Air Temperature, T, °F:	1,000		
Dilution Air/Primary Air Ratio:			
R = (T2-T)/(T-T1))*(Cp2;/Cp1) =	4.30		
Total Air, lb/MMBtu of Fuel:	3,835		
Dilution Air, lb/MMBtu of Fuel:	3,112		
Total Flue Gas, lb/MMBtu of Fuel:	3,877		
Design Flue Gas Discharge Temp., T3, °F:	300		
Available Heat, MMBtu/MMBtu of Fuel:	0.80		
Fuel Req'm't, MMBtu of Fuel/MMBtu of Heat:	1.25		

TABLE B-4 (continued)

SPRAY DRYER PROCESS CALCULATIONS - CASE I

3. TOTAL PROCESS REQUIREMENT:

Heat Loss Thru Insulation, % of Process:	20
Total Heat Requirement, (ideal), MMBtu/hr:	15.84
Total Heat Requirement, (actual), MMBtu/hr:	19.01
Total Fuel Requirement, MMBtu/hr:	19.85
lb/hr:	831
Total Air Requirement, lb/hr:	76,139
SCFM:	16,685
Total Flue Gas, lb/hr:	76,970
SCFM:	16,810
Water Evaporated, SCFM:	5,574
Total Exhaust Flow, SCFM:	22,383
Pressure Drop Allowance, inch of water:	12
psi:	0.41
Blower Power Requirement, BHP:	102.9
kWh:	76.8
Feed Pump Head Requirement, ft:	80
Feed Pump Power Requirement, BHP:	1.30
kWh:	0.97

TABLE B-5

SPRAY DRYER PROCESS CALCULATIONS - CASE II

1. DESIGN BASIS:

Brine Flow from Multiple Effect Evaporator, lb/day:	86,900
Sale Concentration, % wt:	10
Brine Temperature, °F:	215
Total Water Removal, lb/hr:	3,259

2. COMBUSTION AIR REQUIREMENT:

Assumed Fuel Type:	Natural Gas
HHV, Btu/SCF:	1,015
Btu/lb of Methane:	23,879
Specific Heating Value, lb/MMBtu:	41.88
Stoichiometric Combustion:	

	/lb Fuel	/MMBtu	Cp
Combustion Air Requirement, lb:			
O_2	3.99	167.09	
N_2	13.28	556.14	
TOTAL	17.27	723.23	
Specific Heat of Air, Cp1, Btu/°F, lb:			0.262
Combustion Products:			
CO_2	2.74	114.75	0.28
H_2O	2.25	94.23	1.51
N_2	13.28	556.14	0.27
TOTAL PRODUCTS	18.27	765.11	
Sp. Ht. of Combustion Products, Cp2, Btu/°F, lb:			0.42
Molecular Weight:	29.17		
Flame Temperature, T2, °F:	3,551		
Assumed Ambient Temperature, T1, °F:	40		
Specified Drying Air Temperature, T, °F:	1,000		
Dilution Air/Primary Air Ratio: R = (T2-T)/(T-T1))*(Cp2;/Cp1) =	4.30		
Total Air, lb/MMBtu of Fuel:	3,835		
Dilution Air, lb/MMBtu of Fuel:	3,112		
Total Flue Gas, lb/MMBtu of Fuel:	3,877		
Design Flue Gas Discharge Temp., T3, °F:	300		
Available Heat, MMBtu/MMBtu of Fuel:	0.80		
Fuel Req'm't, MMBtu of Fuel/MMBtu of Heat:	1.25		

TABLE B-5 (continued)

SPRAY DRYER PROCESS CALCULATIONS - CASE I

3. TOTAL PROCESS REQUIREMENT:

Heat Loss Thru Insulation, % of Process:	20
Total Heat Requirement, (ideal), MMBtu/hr:	3.26
Total Heat Requirement, (actual), MMBtu/hr:	3.91
Total Fuel Requirement, MMBtu/hr:	4.08
lb/hr:	171
Total Air Requirement, lb/hr:	15,663
SCFM:	3,432
Total Flue Gas, lb/hr:	15,834
SCFM:	3,458
Water Evaporated, SCFM:	1,147
Total Exhaust Flow, SCFM:	4,605
Pressure Drop Allowance, inch of water:	12
psi:	0.41
Blower Power Requirement, BHP:	21.2
kWh:	15.8
Feed Pump Head Requirement, ft:	80
Feed Pump Power Requirement, BHP:	0.27
kWh:	0.20

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